India's

Initial National Communication to the United Nations Framework Convention on Climate Change

सत्यमेव जयते

Government of India

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Ministry of Environment & Forests
Government of India
2004

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United Nations Framework Convention on Climate Change

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FOREWORD

On behalf of the Government of India, I have great pleasure in presenting India's Initial National Communication in fulfillment of our commitment in this respect under the United Nations Framework Convention on Climate Change. The Communication has been prepared by a national effort involving more than 350 scientific personnel constituted into 131 multi-disciplinary teams. This exercise was coordinated by the Ministry of Environment & Forests. The Communication has been prepared in terms of the requirements of Article 12 of the Convention and in accordance with the relevant decisions of the Conference of Parties. We committed to maintain the highest standards of scientific rigour in conducting this exercise and the research outputs underpinning the National Communications has been extensively peer revived.

This national effort has built up human and institutional capacities in the different disciplines related to the preparation of this Initial National Communication. However, we are aware and have identified in our Communication the constraints and the gaps that still exist, and the related financial and capacity building needs, which are required to further improve upon this effort in our future National Communications.

I congratulate all those who have been involved in this national task. The Government of India is also thankful to the UNDP-GEF for providing the necessary financial support for conducting this exercise.

(A. Raja)

Place: New Delhi

Dated: 16.06.2004

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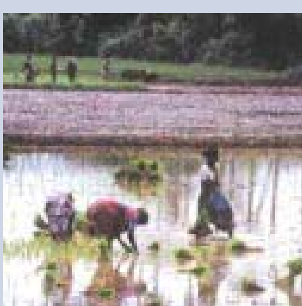
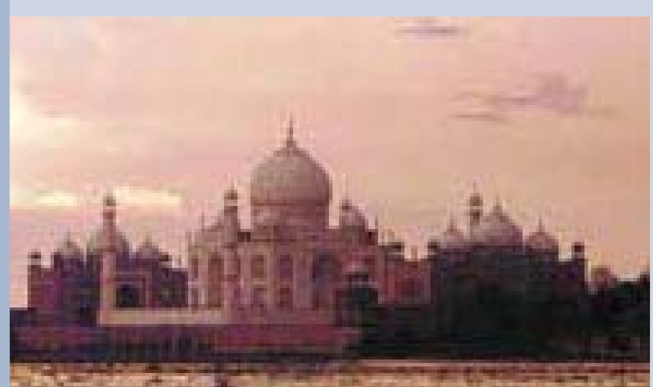
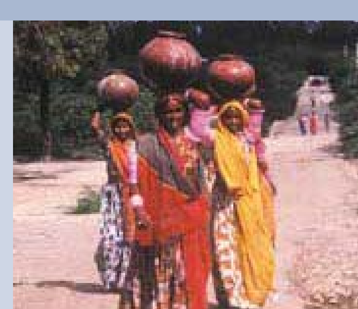






Executive Summary

India is a Party to the United Nations Framework Convention on Climate Change (UNFCCC) and the Government of India attaches great importance to climate change issues. The Convention aims to stabilize greenhouse gas concentrations in the atmosphere at levels that would prevent dangerous anthropogenic interference with the climate system. Eradication of poverty, avoiding risks to food production, and sustainable development are three principles embedded in the Convention. Information provided in the Initial National Communication is in terms of guidelines prescribed for Parties not included in Annex I to the UNFCCC and the inventory is prepared for the base year 1994 as stipulated.

India is a vast country covering 3.28 million km^2 with diverse surface features. India occupies only 2.4 per cent of the world's geographical area, but supports 16.2 per cent of the global human population. India is endowed with varied soils, climate, biodiversity and ecological regimes. Under such diverse natural conditions, over a billion people speaking different languages, following different religions and living in rural and urban areas, live in harmony under a democratic system.

NATIONAL CIRCUMSTANCES

India's land surface may be classified as (a) the Great Mountain Wall of the North; (b) the Northern Plains; (c) the Great Southern Peninsular Plateau; (d) the Coastal Plains; and (e) the Islands. India's unique geography produces a spectrum of climates yielding a wealth of biological and cultural diversity. Land areas in the north have a continental climate with high summer temperatures with cold winters when temperatures may go below freezing. In contrast are the coastal regions of the country where the temperature is more even throughout the year and rains are more frequent. There is large variation in the amounts of rainfall received in different parts of the country. Average annual rainfall is less than 13 cm in the Thar desert, while at Cherrapunji in the North-East it is as high as 1080 cm. The different climate regimes of the country vary from humid in the North-East (about 180 days rainfall in a year) to arid in Rajasthan (20 days rainfall in a year). A semi-arid belt in the peninsular region extends in the area between the humid west coast and the central and eastern parts of the country. The most important feature of India's climate is the season of concentrated rain called the "monsoon". The Southwest (SW) monsoon (May - September) is the most important feature of the Indian climate.

India is a land with many rivers. The twelve major rivers spread over a catchment area of 252.8 million hectares (Mha) cover more than 75 per cent of the total area of the country. Rivers in India are classified as Himalayan, Peninsular, Coastal, and Inland-drainage basin rivers.

The land use pattern is influenced by diverse factors such as population density, urbanization, industry, agriculture, animal husbandry, irrigation demands, and natural calamities like floods and droughts. Despite stresses, the area under forests has increased in recent years due to proactive reforestation and afforestation programmes of the Government of India. Presently 23 per cent of the total land area is under forest and tree cover, while 44 per cent is net sown area. The remaining one-third is roughly equally distributed between fallow land, non-agricultural land, and barren land.

The panorama of Indian forests ranges from evergreen tropical rain forests in the Andaman and Nicobar Islands, the Western Ghats, and the North-east, to dry alpine scrub high in the Himalayas in the north. Between these extremes, the country has semi-evergreen rain forests, deciduous monsoon forests, thorn forests, subtropical pine forests in the lower montane zone, and temperate montane forests. According to the Forest Survey of India, the total forest cover in the year 2000 was 6,75,538 km^2.

India is a largely agrarian society with nearly 64 per cent of the population dependent on agriculture, although the share of agriculture in the gross domestic product has been continuously declining over the last 50 years. Crop production in India takes place in almost all land class types, namely, dry, semi dry, moist, sub humid, humid, fluvisols and gleysols. Agriculture will continue to be important in India's economy in the years to come as it feeds a large and growing population, employs a large labour force, and provides raw material to agro-based industries.

India is the second most populous country in the world. The population crossed the one billion mark in 2000. The decadal population growth rate has steadily declined from 24.8 per cent during 1961-1971 to 21.3 per cent during 1991-2001 and is expected to further decline to 16.2 per cent during 2001-2011, due to various policies of the Government of India relating to family welfare, education, health and empowerment of women.

India had more than 160 million households in 1994. Nearly three fourths of these households live in rural areas, accounting for one-third of total national primary energy consumption. With rising incomes, households at all socioeconomic levels are increasingly using energy using devices such as electric bulbs, fans, televisions, refrigerators, washing machines, air-coolers, air-conditioners, water heaters, scooters and cars. The related greenhouse gas (GHG) emissions will continue to rise even though the energy efficiencies of the appliances are continually improving.

GDP (at factor cost and constant prices) grew by 7.2 per cent in the fiscal year 1994. In the decade following 1990s, the annual average GDP growth rate was 6.6 per cent making India one of the 10 fastest growing economies of the world. Key socio-economic indicators for 1994 are presented in Table 1.

The Indian economy has made enormous strides since independence in 1947, achieving self-sufficiency in food for a rising population, increasing per capita GDP by over three-times, reducing illiteracy and fertility rates, creating a strong and diversified industrial base, building up infrastructure, developing technological capabilities in sophisticated areas and establishing growing linkages with the world economy. However, much remains to be achieved and the Government of India is committed to developmental targets that are more ambitious than the United Nations Millennium Development Goals. The high incidence of poverty underlines the need for rapid economic development to create more remunerative employment and for investment in social infrastructure such as health and education. Notwithstanding the climate friendly orientation of national policies, the development to

Table 1: National circumstances, 1994

Criteria	1994
Population (million)	914
Area (million square kilometers)	3.28
GDP at Factor cost 1994-95 (1993-94 prices) Rs billion	8,380
GDP at Factor cost 1994-95 (1993-94 prices) US$ billion	269
GDP per capita (1994 US$)	294
Share of industry in GDP for 1994-95 (per cent)	27.1
Share of services in GDP for 1994-95 (per cent)	42.5
Share of agriculture in GDP for 1994-95 (per cent)	30.4
Land area used for agricultural purposes (million square kilometers)	1.423
Urban population as percentage of total population	26
Livestock population excluding poultry (million)	475
Forest area (million square kilometers)	0.64
Population below poverty line (per cent)	36
Life expectancy at birth (years)	61
Literacy rate (per cent)	57

Note: The monthly per capita income poverty lines for rural and urban areas are defined as Rs. 228 and Rs. 305 respectively for 1994-95.

Sources: Economic Survey 1995-1996 and 2000-01. Economic Division, Ministry of Finance, Government of India; Census of India, 1991 and 2001. Government of India.

meet the basic needs and aspirations of a vast and growing population will lead to increased GHG emissions in the future.

Energy use during the past five decades has expanded, with a shift from non-commercial to commercial energy. Among commercial energy sources, the dominant source is coal with a share of 47 per cent. The dominance of coal is because India is endowed with significant coal reserves of about 221 Bt (billion tonnes) that is expected to last much longer than its oil and natural gas reserves. The shares of petroleum and natural gas in the total commercial energy used in the country are 20 percent and 11 percent respectively. The total renewable energy consumption including biomass amounts is about 30 per cent of the total primary energy consumption in India. A number of steps are being initiated to develop renewable sources of energy in a systematic manner. However, coal being abundant, cheap and locally available would remain mainstay of the Indian energy system for energy security reasons.

GREENHOUSE GAS INVENTORY INFORMATION

The 1994 inventory of greenhouse gases for India provides a comprehensive estimate of emissions by sources and removals by sinks of carbon dioxide, methane and nitrous oxide not controlled by the Montreal Protocol. The GHG inventory is reported in terms of the non-Annex 1 guidelines (Table 2). For a transparent and comparable inventory, the revised Intergovernmental Panel on Climate Change (IPCC) guidelines prescribed for development of national GHG inventories have been applied. A major effort has been devoted towards improving the basis for preparing the inventory, which involves use of activity data and country specific greenhouse gas emission coefficients. Emission coefficients in key sectors have been developed which include CO_2 emission coefficients for Indian coal types, CO_2 and CH_4 emission coefficients for road vehicles, CH_4 emission coefficients for coal mining, enteric fermentation, and rice cultivation.

In 1994, 1,228,540 Gg of CO_2-eq of anthropogenic greenhouse gases (GHGs) were emitted from India resulting in a per capita emission of about 1.3 tons. CO_2 emissions were the largest at 793,490 Gg, i.e. 65 per cent of the total national CO_2-eq emissions. The shares of CH_4 and N_2O were 31 per cent (18,082 Gg) and 4 per cent (178 Gg), respectively (see Figure 1a). Details of GHG emissions by sector are given in Table 2. Of the total CO_2-eq emissions in 1994, the largest share of 61 per cent was contributed by the all energy sector, followed by the agriculture sector at 28 per cent, industrial process at 8 per cent, waste at 2 per cent and land use, land use change and forestry at 1 per cent (see Figure 1b).

Total CO_2 emitted in 1994 from all the above sectors was 817,023 Gg and removal by sinks was 23,533 Gg resulting in net emission of 793,490 Gg of CO_2. This constituted 65 per cent of the total GHG released in 1994. CO_2 emissions were contributed by activities in the energy sector, industrial processes, and land use, land use change and forestry (LULUCF). The relative shares of the three sectors to the total CO_2 released from the country were 85 per cent, 13 per cent and 2 per cent, respectively (see Figure 2). The industrial process sector, which includes processes such as iron and steel manufacturing and cement production, is also a major source of CO_2. Whereas

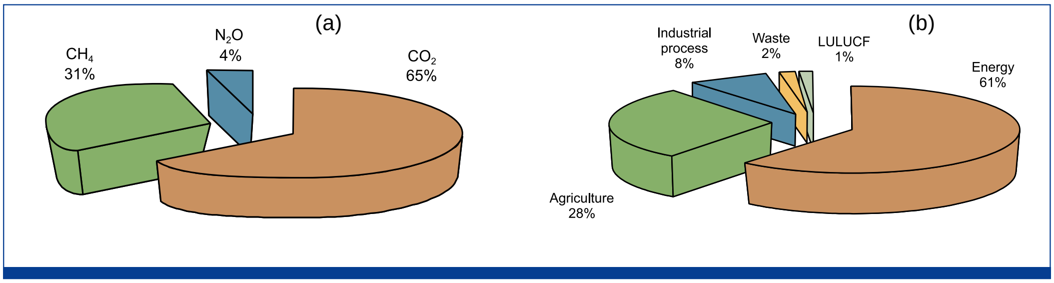


Figure 1: Distribution of GHG emissions from India in 1994 (a) Gas by Gas emission distribution (b) sectoral distribution of CO_2 equivalent emissions.

Table 2: India's national greenhouse gas inventories in Gigagram (Gg) of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol for the base year 1994.

Greenhouse gas source and sink categories (Giga gram per year)	CO_2 emission	CO_2 removals	CH_4 emission	N_2O emission	CO_2 eq. emission*
Total (Net) National Emission	**817023**	**23533**	**18083**	**178**	**1228540**
1. All Energy	**679470**		**2896**	**11.4**	**743820**
Fuel combustion					
Energy and transformation industries	353518			4.9	355037
Industry	149806			2.8	150674
Transport	79880		9	0.7	80286
Commercial-institutional	20509			0.2	20571
Residential	43794			0.4	43918
All other sectors	31963			0.4	32087
Biomass burnt for energy			1636	2.0	34976
Fugitive Fuel Emission					
Oil and natural gas system			601		12621
Coal mining			650		13650
2. Industrial Processes	**99878**		**2**	**9**	**102710**
3. Agriculture			**14175**	**151**	**344485**
Enteric Fermentation			8972		188412
Manure Management			946	1	20176
Rice Cultivation			4090		85890
Agricultural crop residue			167	4	4747
Emission from Soils				146	45260
4. Land use, Land-use change and Forestry*	**37675**	**23533**	**6.5**	**0.04**	**14292**
Changes in Forest and other woody biomass stock		14252			(14252)
Forest and Grassland Conversion	17987				17987
Trace gases from biomass burning			6.5	0.04	150
Uptake from abandonment of Managed lands		9281			(9281)
Emissions and removals from soils	19688				19688
5. Other Sources as appropriate and to the extent possible					
5a. Waste			**1003**	**7**	**23233**
Municipal Solid Waste Disposal			582		12222
Domestic Waste water			359		7539
Industrial Waste Water			62		1302
Human Sewage				7	2170
5b. Emission from Bunker fuels #	**3373**				**3373**
Aviation	2880				2880
Navigation	493				493

Not counted in the national totals.

*Converted by using Global warming potential (GWP) indexed multipliers of 21 and 310 for converting CH_4 and N_2O respectively to CO_2 equivalents.

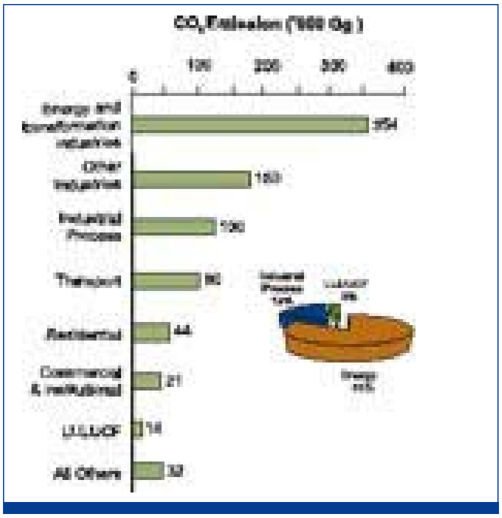


Figure 2: Sectoral CO_2 emissions in 1994.

CO_2 emissions from energy sector include emissions from fossil fuel combustion throughout the economy, CO_2 emissions from biomass fuels are treated as carbon neutral and therefore not included in the national totals.

Total national CH_4 emission in the year 1994 was 18,583 Gg. Of this the share of agriculture sector was 78 per cent. Emission due to enteric fermentation (8,972 Gg) and rice cultivation were the highest (4,090 Gg) sources of CH_4 emission in the agriculture sector.

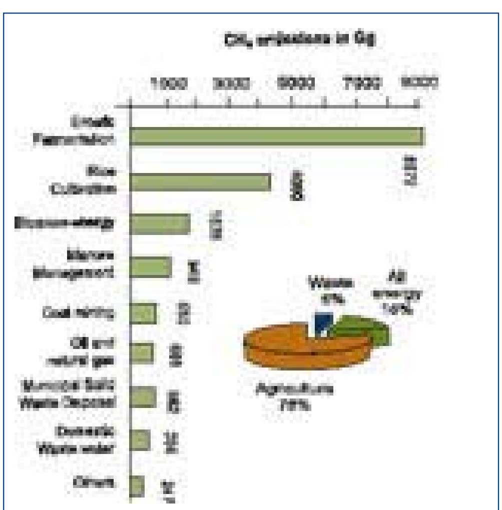


Figure 3: Sectoral CH_4 emission in 1994.

16 per cent of the total CH_4 emissions came from energy sources such as biomass burning, coal mining and handling, and flaring of natural gas systems. Waste disposal activities contributed about 6 percent of the total CH_4 emission. Methane emitted from land use, land use change and forestry sector was minor and was due to the burning of biomass in shifting cultivation practices. Similarly, CH_4 emitted from Industrial processes was only 2 Gg . The sectoral distribution of CH_4 emitted from various sources in 1994 is shown in Figure 3.

Total N_2O emission in 1994 was 178 Gg contributing 4 per cent of the total GHG emissions. Significant emission of N_2O was from the agriculture sector, which accounted for 84 per cent of total N_2O emission. Fuel combustion accounted for 7 per cent of the emission; industrial processes 5 per cent, and waste 4 per cent (see Figure 4). Emission from biomass burning was insignificant.

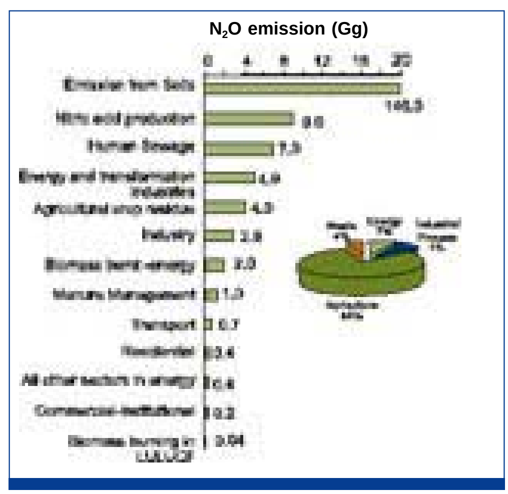


Figure 4: Sectoral N_2O emissions in 1994.

VULNERABILITY ASSESSMENT AND ADAPTATION

India has reasons to be concerned about the impacts of climate change. Its large population depends on climate-sensitive sectors like agriculture and forestry for livelihoods. Any adverse impact on water availability due to recession of glaciers, decrease in rainfall and increased flooding in certain pockets would threaten food security, cause die back of natural ecosystems including species that sustain the livelihoods of rural households, and adversely impact the coastal system due to sea level rise and increased frequency of extreme events. Apart from these, achievement of vital national development goals related to other systems such as habitats, health, energy demand, and infrastructure investments would be adversely affected.

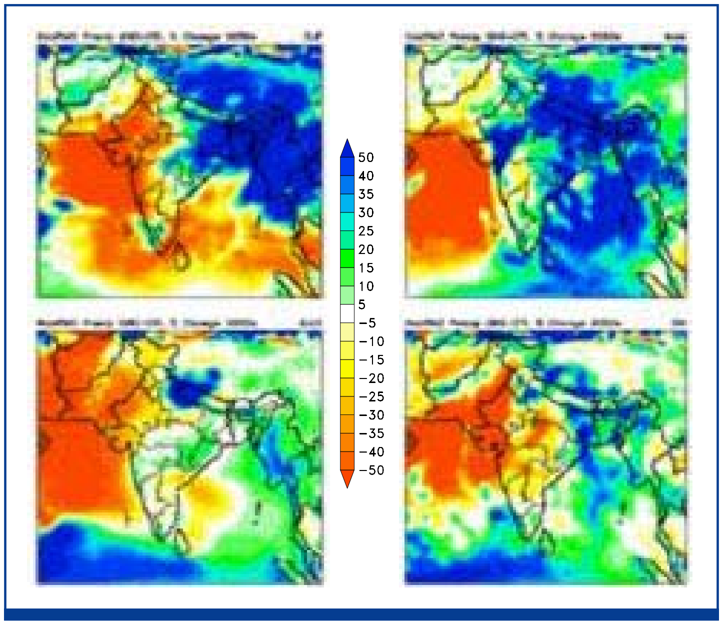


Figure 6:. Projections of seasonal precipitation for the period 2041-60, based on the regional climate model HadRM2.

Climate projections: Significant increase of the order of 0.4°C in the past one hundred years in the annual global average surface air temperature has already been observed. While annual average monsoon rainfall at the all-India level for the same period has been without any trend and variations have been random in nature, increase in monsoon seasonal rainfall have been recorded along the west coast, north Andhra Pradesh and north-west India (+10 to +12 per cent of normal/100 years) while decreasing trends have been observed over east Madhya Pradesh and adjoining areas, north-east India and parts of Gujarat and Kerala (-6 to -8 per cent of normal/100 years). Using the second generation Hadley Center Regional Model (Had RM2) and the IS92a future scenarios of increased greenhouse gas concentrations, marked increase in seasonal surface air temperature is projected into the 21st century, becoming conspicuous after the 2040s (Figure 5). Climate projections indicate increases in both maximum as well as minimum temperatures over the region south of 25°N, the maximum temperature is projected to increase by 2-4°C during the 2050s. In the northern region the increase in maximum temperature may exceed 4°C. Model projections also indicate an increase in minimum temperature by 4°C

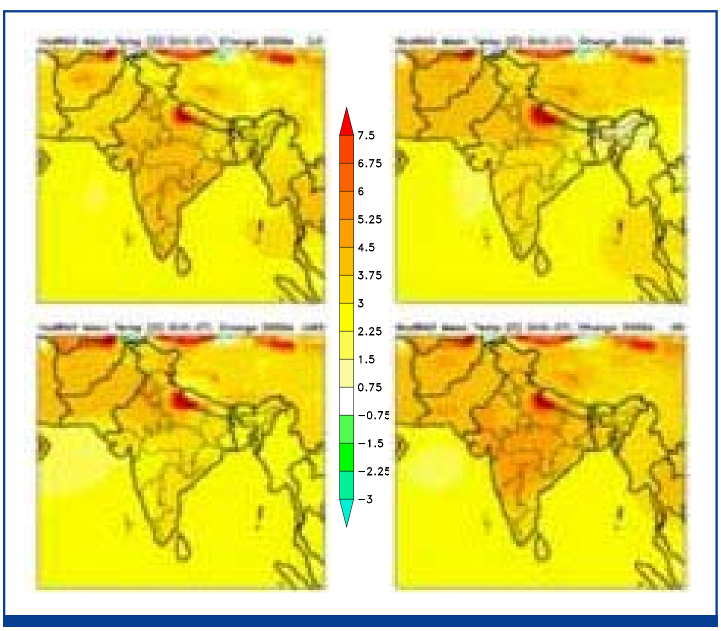


Figure 5:. Projections of seasonal surface air temperature for the period 2041-60, based on the regional climate model HadRM2.

all over the country, which may increase further in the southern peninsula. Little change in monsoon rainfall is projected up to the 2050s at the all-India scale level (Figure 6). However there is an overall decrease in the number of rainfall days over a major part of the country. This decrease is greater in the western and central parts (by more than 15 days) while near the Himalayan foothills (Uttaranchal) and in northeast India the number of rainfall days may increase by 5-10 days. Increase in rainfall intensity by 1-4 mm/day is expected all over India, except for small areas in northwest India where the rainfall intensities may decrease by 1 mm/day.

Assessment of the projections of future climate by different GCMs show a consistent rise in temperature across all models, indicating that these predictions are robust. However, the projections of rainfall vary across models. Though the climate models used for assessing future climate have their inherent limitations and uncertainties, the results obtained through these models give an indication of the likely changes in climate in the future. The consequences of these expected changes would vary greatly across the length and breadth of India due to its complex geography and climate patterns. Regional and sectoral variability in levels of social and economic development requires in-depth regional and sectoral assessment of vulnerability due to the projected climate change, and formation of adaptation strategies. The information available for assessments of impact is fragmentary. An effort was made during preparation of the Initial National Communication to undertake modeling and research studies and collate existing information on impact assessment and development strategies which may mitigate some impacts.

Water resources: Water is a precious natural resource supporting human activities and ecosystems, and at the same time very complex to manage judiciously. The hydrological cycle, a fundamental component of climate, is likely to be altered in important ways due to climate change. Using the SWAT (Soil and Water Assessment Tool) water balance model for hydrologic modeling of different river basins in the country, in combination with the outputs of the HadRM2 regional climate model, preliminary assessments have revealed that under the IS92a scenario, the severity of droughts and intensity of floods in various parts of India is likely to increase. Further, there is a general reduction in the quantity of available runoff under the IS92a scenario. River basins of Sabarmati and Luni, which occupy about one quarter of the area of Gujarat and 60 percent of the area of Rajasthan, are likely to experience acute water scarce conditions. River basins of Mahi, Pennar, Sabarmati and Tapi are likely to experience constant water scarcity and shortage. River basins of the Cauvery, Ganga, Narmada and Krishna are likely to experience seasonal or regular water stressed conditions. River basins of the Godavari, Brahmani and Mahanadi are projected to experience water shortages only in a few locations (Figure 7).

Figure 7: Broad variation in vulnerability of different regions to projected climate change.

Ground water inventory is presently 0.34 million km^3. Although efforts are being made to promote improved water management practices such as water conservation, artificial recharge and watershed management, and integrated water development, the projected water demand of over 980 billion cubic meters in 2050 will require intensive development of ground water resources, exploiting both dynamic and in-storage potential.

It is obvious that the projected climate change resulting in warming, sea level rise and melting of glaciers will adversely affect the water balance in different parts of India and quality of ground water along the coastal plains. Climate change is likely to affect ground water due to changes in precipitation and evapotranspiration. Rising sea levels may lead to increased saline intrusion into coastal and island aquifers, while increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. Increased rainfall intensity may lead to higher runoff and possibly reduced recharge.

Agriculture sector: Food grain production in India has increased from 50 million tons in 1951 to 212 million tons in 2002, while the mean cereal productivity has increased from 500 kg ha^{-1} to almost 1800 kg ha^{-1}. Despite this progress, food production in India, is still considerably dependent on the rainfall quantity and its distribution, which is highly variable spatially as well as temporally. In the past fifty years, there have been around 15 major droughts, due to which the productivity of rainfed crops in drought years was adversely affected.. Limited options of alternative livelihoods and widespread poverty continue to threaten livelihood security of millions of small and marginal farmers in the rainfed agriculture region. Food security of India may be at risk in future due to the threat of climate change leading to increase in frequency and intensity of droughts and floods, thereby affecting production on small and marginal farms.

Simulations using dynamic crop models, having the flexibility to independently assess the impacts of temperature rise and CO_2 increase on crop production, indicate a decrease in yield of crops as temperature increases in different parts of India. These reductions were, however, generally offset by the increase in CO_2; the magnitude of this response varied with crop, region, and climate change ("pessimistic" or "optimistic", "pessimistic" scenario refer to high increase in temperature and low increase in CO_2, while "optimistic" scenario refers to large increase in CO_2 and a low change in temperature). Irrigated rice yields may have a small gain, irrespective of the scenario throughout India. Wheat yields in central India are likely to suffer drop in crop yield up to 2 per cent in pessimistic scenario but there is also a possibility that yields may increase by 6 per cent if the global change is optimistic. Sorghum, being a C4 plant, does not show any significant response to increase in CO_2 and hence these scenarios are unlikely to affect its yield. However, if the temperature increases are higher, western India may show some negative effect on productivity due to reduced crop durations.

Forest eco-systems: Preliminary assessments using BIOME-3 vegetation response model, based on regional climate model projections (HadRM2) for India show shifts in forest boundary, changes in species-assemblage or forest types, changes in net primary productivity, possible forest die-back in the transient phase, and potential loss or change in biodiversity. Enhanced levels of CO_2 are projected to result in an increase in the net primary productivity (NPP) of forest ecosystems over more than 75 per cent of the forest area. Even in a relatively short span of about 50 years, most of the forest biomes in India seem to be highly vulnerable to the projected change in climate (Figure 8). About 70 per cent of the vegetation in India is likely to find itself less than optimally adapted to its existing location, making it more vulnerable to the adverse climatic conditions as well as to the increased biotic stresses. Biodiversity is also likely to be adversely impacted. These impacts on forests will have adverse socio-economic implications for forest-dependent communities and the national economy. The impacts of climate change on forest ecosystems are likely to be long-term and irreversible. Thus, there is a need for developing and implementing adaptation strategies to minimize possible adverse impacts. Further, there is a need to study and identify the forest policies, programmes and silvicultural practices that contribute to vulnerability of forest ecosystems to climate change.

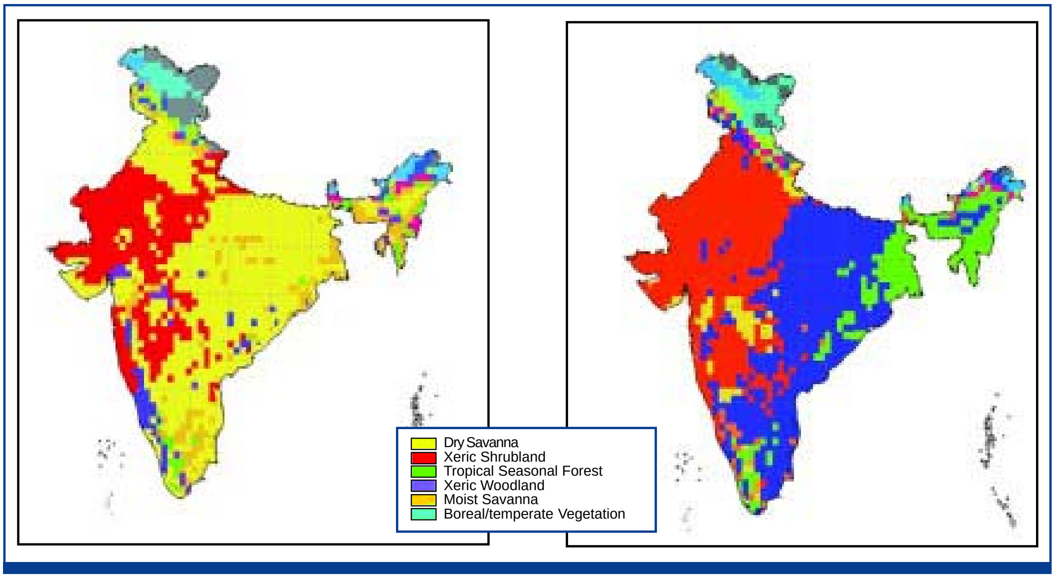


Figure 8: Vegetation map for the year 2050 (right) under GHG run of HadRM2 considering all grids of India and potential vegetation (including grids without forests). The control run (without GHG increase) is shown on the left.

Natural ecosystems: Natural ecosystems such as grasslands, mangroves, and coral reefs are also likely to be affected by climate change. Increasing atmospheric CO_2 levels would favour C3 plants over C4 grasses, but the projected increases in temperature would favor the C4 plants. Climate change would thus be region-specific and involve a complex interaction of factors. Sea level rise would submerge mangroves as well as increase the salinity of wetlands. This would favour mangrove plants that tolerate higher salinity. Increased snowmelt in the western Himalayas could bring larger quantities of fresh water into the Gangetic delta. This would have significant consequences for the composition of the Sundarbans mangroves, favoring mangrove species that have relatively lower tolerance to salinity. The projected sea-level rise of 0.09-0.88 m between the years 1990 and 2100 seems within the ability of Sundarbans mangrove ecosystem, which presently face tidal amplitudes up to 5 m, to adapt. This may not be true for other mangroves such as the Pichavaram and Muthupet where tidal amplitudes are much lower at 0.64 m and much of the inland areas are already under agriculture. Changes in local temperature and precipitation would also influence the salinity of the mangrove wetlands and have a bearing on plant composition.

An increase in sea-surface temperature would lead to the bleaching of corals. Coral reefs could also be potentially impacted by sea-level rise. Healthy reef flats seem able to adapt through vertical reef growth of 1 cm per year, that is within the range of the projected sea-level rise over the next century. However, the same may not be true for degraded reefs that are characteristic of densely populated regions of South Asia.

Coastal zone: The coastal zone is an important and critical region for India. It is densely populated and stretches over 7,500 km with the Arabian Sea in the West and Bay of Bengal in the East. The total area occupied by coastal districts is around 379,610 km^2, with an average population density of 455 persons per km^2, which is about 1.5 times the national average of 324 persons per km^2. Under the present climate, it has been observed that the sea-level rise (0.4-2.0 mm/year) along the Gulf of Kutchh and the coast of West Bengal is the highest. Along the Karnataka coast, however, there is a relative decrease in the sea level.

Future climate change in the coastal zones is likely to be manifested through worsening of some of the existing coastal zone problems. Some of the main

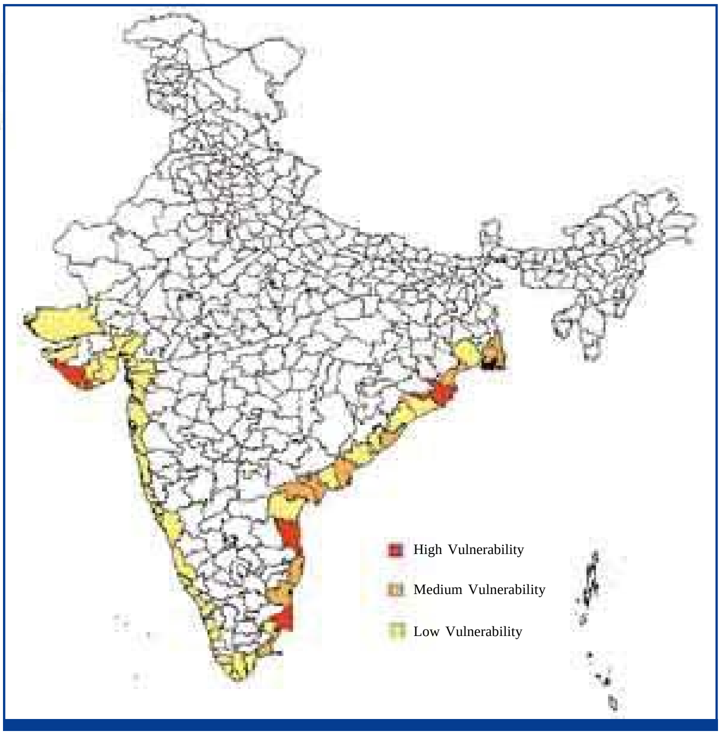


Figure 9: Coastal districts vulnerable to climate change.

climate-related concerns in the context of the Indian coastal zones are erosion, flooding, submergence and deterioration of coastal ecosystems, such as mangroves and salinization. In many cases, these problems are either caused by, or exacerbated by, sea-level rise and tropical cyclones. The key climate-related risks in the coastal zone include tropical cyclones, sea-level rise, and changes in temperature and precipitation. A rise in sea level is likely to have significant implications on the coastal population and agricultural performance of India. A one-metre sea-level rise is projected to displace approximately 7.1 million people in India and about 5,764 square kilometers of land area will be lost, along with 4,200 km of roads.

The diverse impact expected as a result of sea-level rise include land loss and population displacement, increased flooding of low-lying coastal areas, loss of yield and employment resulting from inundation, and salinization. Damage to coastal infrastructure, aquaculture and coastal tourism, due to the erosion of sandy beaches, is also likely. The extent of vulnerability, however, depends not just on the physical exposure to sea-level rise and the population affected, but also on the extent of economic activity of the areas and capacity to cope with impacts (see Figure 9).

Human health: The overall susceptibility of the Indian population to environmental health concerns has decreased in recent years as a result of the improvement in access to health facilities. The extent of access to and utilization of health care varies substantially between states, districts and different segments of society. To a large extent, this is responsible for substantial differences between states in health indices of the population. During the 1990s, the mortality rates reached a plateau, and India entered an era of dual disease burden. Communicable diseases have become more difficult to combat because of the development of insecticide resistant strains of vectors. Malaria is one such disease in India that has been prevalent over the years, despite government efforts to eradicate it. The climate, vegetation and other socioeconomic parameters conducive to its prevalence are consistently present in some regions of India. It is projected that malaria will move to higher latitudes and altitudes in India, with 10 per cent more area offering climatic opportunities for the malaria vector to breed throughout the year during the 2080s with respect to the year 2000 (see Figure 10).

Infrastructure and energy: Large investments are being committed to new infrastructure projects, such as improving drinking water availability, construction of roads and highways, the cost of which runs into billions of US dollars. Infrastructure being long-life assets are designed to withstand normal variability in climate regime. However, climate change can affect both average conditions and the probability of extreme events, temperatures, precipitation patterns, water

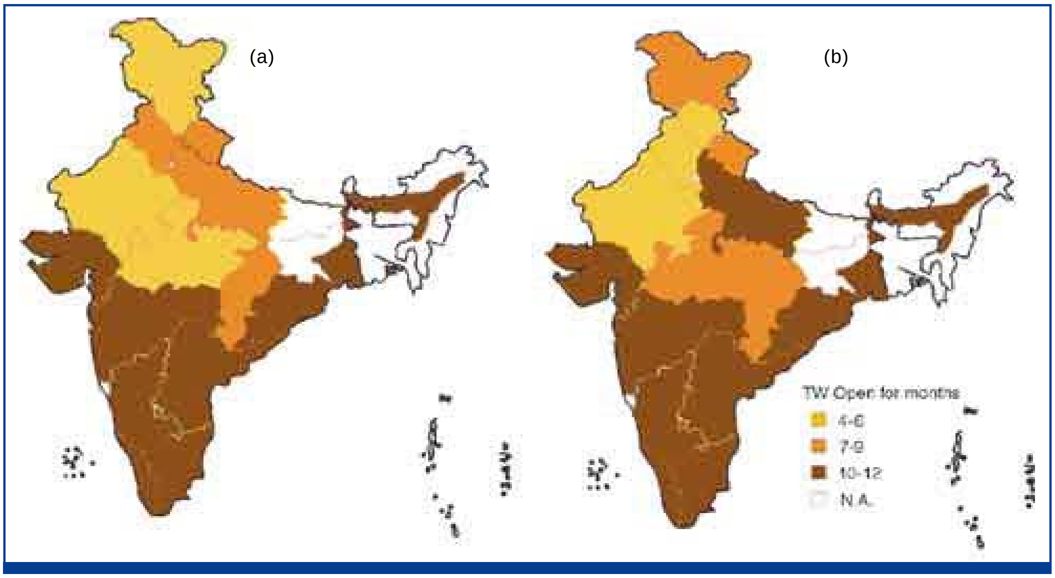


Figure 10: Transmission window of malaria in different states of India.
(a) for 2000 and (b) under projected climate change scenario during the 2080s.

availability, flooding and water logging, vegetation growth, land slides and land erosion in the medium and long-run which may have serious impacts on infrastructure. These are likely to lead to huge monetary losses, if not taken into consideration while planning. Studies indicate that increased temperatures would increase space-cooling requirements, while enhanced groundwater demand would increase water-pumping requirements. These will enhance the electricity demand and add costs to the consumers for maintaining their lifestyles, as well as to the electricity production systems.

The projected variability in precipitation can impact the irrigation needs and consequently increase electricity demand in agriculture sector. This would result in the need for higher power generation capacity. Also, about 1.5 per cent additional power generation capacity would be required for enhanced space cooling requirements as a result of increase in temperature. These additional power requirements are likely to be partly offset by adoption of various energy conservation measures in these areas as the projected energy saving potential in these sectors is very high. However, implementation of energy conservation measures would require substantial investments.

Though the Government of India has taken many policy decisions that reduce risks and enhance the adaptive capacity of the most vulnerable sectors and groups by promoting sustainable development, considerable scope exists for including more measures to cover the entire range of impacts due to the present climate variability. Currently, income disparities and high population growth constrain the opportunities and equitable access to the existing social infrastructure. The projected climate change could further accentuate these conditions. The challenge then is to identify opportunities that facilitate the sustainable use of existing resources. Faster economic development with more equitable income distribution, improved disaster management efforts, sustainable sectoral policies, careful planning of capital intensive and climate sensitive long-life infrastructure assets, are some measures that will assist India in reducing its vulnerability to climate change.

RESEARCH AND SYSTEMATIC OBSERVATION

India's observational and research capabilities have been developed to capture its unique geography and specific requirements, and also to fulfil international commitments of data exchange for weather forecasting and allied research activities. Modernized meteorological observations and research in India was initiated more than 200 years ago, in 1793, when the first Indian meteorological observatory was set up at Madras (Chennai). A network of about 90 weather observatories was established in 1875, when the India Meteorological Department was set up. Many data and research networks have since been established for climate dependent sectors, such as agriculture, forestry and hydrology, rendering a modern scientific background to atmospheric science in India. Inclusion of the latest data from satellites and other modern observation platforms, such as automated weather stations, ground-based remote sensing techniques, and ocean data buoys has strengthened India's long-term strategy of building up a self-reliant climate data bank.

Indian researchers have contributed significantly to the global knowledge on climate change by undertaking research and through participation in international scientific processes, especially in the preparation of various assessment reports of the IPCC. The Government of India, under its various programmes, promotes and supports numerous multidisciplinary studies on climate change and related issues, both in the national and international context, such as understanding climate variability, sectoral and sub-regional vulnerability and impact assessments due to climate change, climate modelling, measurement of atmospheric trace constituents, GHG, and integrating climate change concerns into national planning.

The Government of India also makes investments for the promotion of research and development on a continuous basis in various aspects of environmental conservation, including research in climate change and development of new technologies, e.g., renewable energy, afforestation, replacement of hydrocarbons in surface transport by alternative fuels, such as compressed natural gas (CNG) and ethanol. The government has also allowed the mixing of ethanol to the extent of 5 per cent with petrol. However, an understanding of the national circumstances is important for a comprehensive treatment of climate change issues, concerns and opportunities.

Despite the fact that there is growing literature on climate change science and policy, there is a considerable gap of material on developing countries. There is a great need to bridge this gap to enhance understanding on diverse dimensions of climate change problems, and to facilitate global, national and local policy making, keeping in mind the problems of developing countries.

EDUCATION, TRAINING AND PUBLIC AWARENESS

The Government of India has created mechanisms for increasing awareness on climate change issues through outreach and education initiatives in recent years. The Environmental Information System (ENVIS) centres have been set up throughout the country to generate and provide environmental information to decision makers, policy planners, scientists, researchers and students, through web-enabled systems.

The Ministry of Environment and Forests (MoEF) is the coordinating agency in India for Global Learning and Observations to Benefit the Environment (GLOBE). Students collect data on various environmental parameters related to atmosphere, water, soil and vegetation, and report their data to the GLOBE website.

India hosted the Eighth Conference of Parties (COP-8) to the UNFCCC during 23 October to 1 November 2002 in New Delhi. The event helped in generating awareness about climate change among various stakeholders in India. Apart from this, considerable

Students recording temperature data at a GLOBE school's weather station.

awareness has been generated through the process of the initial national communication executed and implemented by the MoEF. It followed a broad-based participatory approach, involving 131 research teams drawn from premier research institutions, universities, government ministries and departments, and non-governmental organizations (NGOs) of repute across the country. The activities included a preparation of the GHG inventory, assessment of vulnerability to climate change and development of adaptation responses, assimilation of information relating to national circumstances, research and systematic observation, education, training and public awareness, and the creation of a data centre and website. While undertaking these activities, 27 sectoral thematic and training workshops and conferences at national and sub-regional levels were organized across the country for capacity building. For dissemination of activities related to India's initial national communication and climate change issues, a website (www.natcomindia.org) has been launched.

Government initiatives, such as the diffusion of renewable energy technologies, joint forest management, water resource management, agricultural extension services, micro financing, web-enabled services for farmers and rural areas, petroleum conservation research and consumer awareness, energy parks for demonstration of clean energy technologies, establishment of the Technology Information, Forecasting & Assessment Council, environmental education in schools and higher education, represent a broad spectrum of initiatives for education, training and public awareness on climate and related issues.

The media, industry associations and civil society have also played active roles. A recent study indicated that out of 50 large Indian corporate houses, more than three-quarters had an environmental policy, sixty per cent had an environment department, and four out of every 10 had formal environment certification (ISO 14001). All the major industry associations have a climate change division and have taken initiatives to conduct training and generate awareness in key areas, such as energy efficiency and other environment friendly projects.

Several civil society initiatives have sought to build capacity and create awareness about climate-friendly issues. Grassroots-level activities are undertaken that seek to improve the ability of communities to manage their natural resources, generate sustainable livelihoods, develop infrastructure, and participate in decision making, thereby improving their capability to cope with climatic stresses.

In addition, numerous capacity-building initiatives have been undertaken in India. A vital aspect of this process has been the participation by the central and state government agencies, research institutions, NGOs and industry. The Government of India has instituted consultative processes for climate change policies. Indian researchers have made significant contributions to international scientific assessments. Awareness workshops and seminars on issues concerning climate change have been conducted across the country over the last decade. However, in the wake of the complexity of climate change issues, the task is far from complete, and assessments in a range of areas and analyses of uncertainties and risks remain to be undertaken.

PROGRAMMES RELATED TO SUSTAINABLE DEVELOPMENT

India's development plans are crafted with a balanced emphasis on economic development and environment. The planning process, while targetting an accelerated economic growth, is guided by the principles of sustainable development with a commitment to a cleaner and greener environment. Planning in India seeks to increase wealth and human welfare, while simultaneously conserving the environment. It emphasizes the promotion of people's participatory institutions and social mobilization, particularly through the empowerment of women, for ensuring environmental sustainability of the development process.

The past few years have witnessed the introduction of landmark environmental measures in India that have targetted conservation of rivers, improvement of urban air quality, enhanced forestation and a significant increase in the installed capacity of renewable energy technologies. These and similar measures, affirmed by the democratic and legislative processes, have been implemented by committing additional resources, as well as by realigning new investments. These deliberate actions, by consciously factoring in India's commitment to the UNFCCC, have realigned economic development to a more climate friendly and sustainable path.

The principal objective of the national development strategy is to reduce the incidence of poverty to 10 per cent by 2012 and provide gainful employment. The target GDP growth rate of 8 per cent during the current decade, therefore, aims to double our per capita income during this period. Achieving these development priorities will require a substantial increase in energy consumption both at macro and micro levels, and consequent rise in GHG emissions. Coal, being the most abundant domestic energy resource, would continue to play a dominant role. The per capita emissions, which are currently a fifth of the world average, can therefore be expected to rise. Even so, our per capita emissions will remain significantly below the current world average during next several years.

India is endowed with diverse energy resources, wherein coal has a dominant share. Therefore, the Indian energy system evolved with a large share of coal in the energy consumption. This, coupled with the rising energy consumption, led to a rising carbon emissions trajectory in the past. However, India's per capita CO_2 emission of 0.87 t-CO_2 in 1994 is still amongst the lowest in the world. It is 4 per cent of the US per capita CO_2 emissions in 1994, 8 per cent of Germany, 9 per cent of UK, 10 per cent of Japan and 23 per cent of the global average. India's energy, power, and carbon intensities of the GDP have declined after the mid-nineties, due to factors such as increased share of service sector in the GDP, and energy efficiency improvements. India has also taken some initiatives to enhance penetration of low carbon-intensive fuels like natural gas and carbon-free sources like renewable energy. The programmes and institutions to promote energy efficiency, energy conservation and renewable technologies were initiated over two decades ago in India. The recent reforms in the energy and power sectors have resulted in accelerated economic growth, improvements in fuel quality, technology stocks, infrastructure, management practices, and lowered the barriers to efficiency.

CONSTRAINTS AND GAPS, AND RELATED FINANCIAL, TECHNICAL AND CAPACITY NEEDS

The Initial National Communication exercise offered an opportunity to enrich and enhance India's experience in identifying constraints, gaps and related financial, technical and capacity needs to adequately fulfill our obligations under the UNFCCC, including the continuing need for improving the quality of national GHG inventories, regional and sectoral assessment of vulnerabilities and adaptation responses, and the communication of information on a continuous basis.

The data needs for continuous reporting have been identified, taking into consideration the data gaps and constraints experienced during the preparation of the initial national communication (Table 3). Measures for improving the future national communication would include designing consistent data reporting formats for continuous GHG inventory reporting, collecting data for formal and informal sectors of the economy, enhancing data depths to move to a higher tier of inventory reporting, and conducting detailed and fresh measurements for Indian emission coefficients.

Several thematic and specific projects are identified for building the research capacity and implementing the climate change project in the country as a part of the preparatory process for national communication. These are representative projects only and do not present an exhaustive elucidation of India's financial and technological needs and constraints. With enhanced scientific understanding and increased awareness, further areas of investigation will be identified.

Capacity building, networking and resource commitment form the core of institutionalizing Indian climate change research initiatives. This involves a shared vision for cooperative research for strengthening and enhancing scientific knowledge and understanding, institutional capacity (instrumentation, modelling tools, data synthesis and data management), technical skills for climate change researchers, inter-agency

Table 3: Key Gaps and Constraints for Sustained National Communication Activities.

Gaps and constraints	Description	Potential measures (Illustrative examples)
Data organization	Published data not available in IPCC friendly formats for inventory reporting.	Design consistent reporting formats.
	Inconsistency in top-down and bottom-up data sets for same activities.	Data collection consistency required.
	Mismatch in sectoral details across different published documents.	Design consistent in reporting formats.
Non-availability of relevant data	Time series data for some specific inventory sub-categories, e.g., municipal solid waste sites.	Generate relevant data sets.
	Data for informal sectors of economy.	Conduct data surveys.
	Data for refining inventory to higher tier levels.	Data depths to be improved.
Non-accessibility of data	Proprietary data for inventory reporting at Tier III level.	Involve industry and monitoring institutions.
	Data not in electronic formats.	Identify critical datasets and digitize.
	Lack of institutional arrangements for data sharing.	
	Time delays in data access.	Awareness generation.
Technical and institutional capacity needs	Training the activity data generating institutions in GHG inventory methodologies and data formats.	Arrange extensive training programmes.
	Institutionalize linkages of inventory estimation with broader perspectives of climate change research.	Wider dissemination activities.
Non-representative emission coefficients	Inadequate sample size for representative emission coefficient measurements in many sub-sectors.	Conduct more measurements.
Limited resources to sustain national communication efforts	Research networks.	Collaborative research, GEF/ international funding.
	India-specific emission coefficients.	Conduct adequate sample measurements for key source categories.
	Vulnerability assessment and adaptation.	Sectoral and sub-regional impact scenario generation, layered data generation and organization, modelling efforts, case studies for most vulnerable regions.
	Data centre and website.	National centre to be established

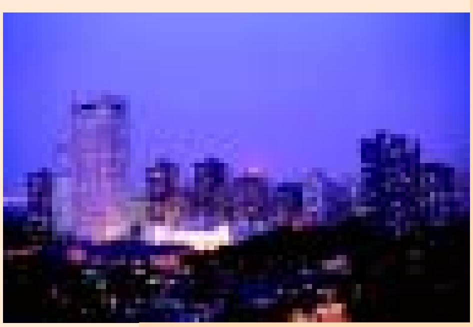
collaboration and networking, and medium to long-term resource commitment.

Capacities thus strengthened and enhanced can be effectively used for the refinement of GHG inventories, development of climate change projections (with reduced uncertainties and at higher resolutions), long-term GHG emission scenarios, detailed impact assessments and formulation of adaptation strategies, developing the capability to undertake integrated impact assessments at sub-regional scales and the diffusion of climate-friendly technologies

Given the magnitude of the tasks, complexities of technology solutions and diversity of adaptation actions envisaged for an improved and continuous reporting of national communications in the future, the incremental financial needs would be substantial for addressing and responding to the requirements of the Climate Change Convention.

Chapter 1

National Circumstances



National Circumstances

Chapter 1

India is a vast country covering 3.28 million km^2, and is situated north of the Equator between 66°E to 98°E and 8°N to 36°N. It is bordered by Nepal, China and Bhutan to the north; Bangladesh and Myanmar to the east; the Bay of Bengal to the south east; the Indian Ocean to the south; the Arabian Sea to the west; and Pakistan to the north west. India consists of diverse physio-geographical features that may be classified into: (a) the Great Mountain Wall (the Himalayan range) in the north; (b) the Northern Plains; (c) the Great Peninsular Plateau; (d) the Coastal Plains; and (e) the Islands. India occupies only 2.4 per cent of the world's land area, but supports about 16.2 per cent of the world's human population. India also has only 0.5 per cent of the world's grazing area, but supports almost a sixth of the world's livestock population. This, as one can imagine, places unbearable stress on both the land and the available natural resources. India is endowed with varied soils, climate, biodiversity and ecological regions. Under such diverse natural conditions, over a billion people speaking different languages, following different religions and inhabiting rural and urban areas, live in harmony under a democratic system.

CLIMATE

India's unique geography produces a spectrum of climates over the subcontinent, affording it a wealth of biological and cultural diversity. The diversity is perhaps greater than any other area of similar size in the world. Land areas in the north of the country have a continental climate with fierce summer heat that alternates with cold winters when temperatures plunge to freezing point. In contrast are the coastal regions of the country, where the warmth is unvarying and the rains are frequent. There is a large variation in the amounts of rainfall received at different locations. The average annual rainfall is less than 13 cm over the Thar desert, while at Cherrapunji in the north-east it is as much as 1080 cm (Figure 1.1). The rainfall pattern roughly reflects the different climate regimes of the country, which vary from humid in the north-east (about 180 days rainfall in a year), to arid in Rajasthan (20 days rainfall in a year)[1]. A semi-arid belt in the peninsular region extends in the area between the humid west coast and the central and eastern parts of the country.

The most important feature of India's climate is the season of concentrated rain called 'the monsoon'. So significant is the monsoon season to the Indian climate, that the rest of the seasons are quite often referred relative to the monsoon.

India is influenced by two seasons of rains, accompanied by seasonal reversal of winds from

Monsoons are the most important feature of India's climate

[1] A rainy day is defined as a day with a rainfall of 2.5 mm and above, as per the operational practice of the India Meteorological Department.

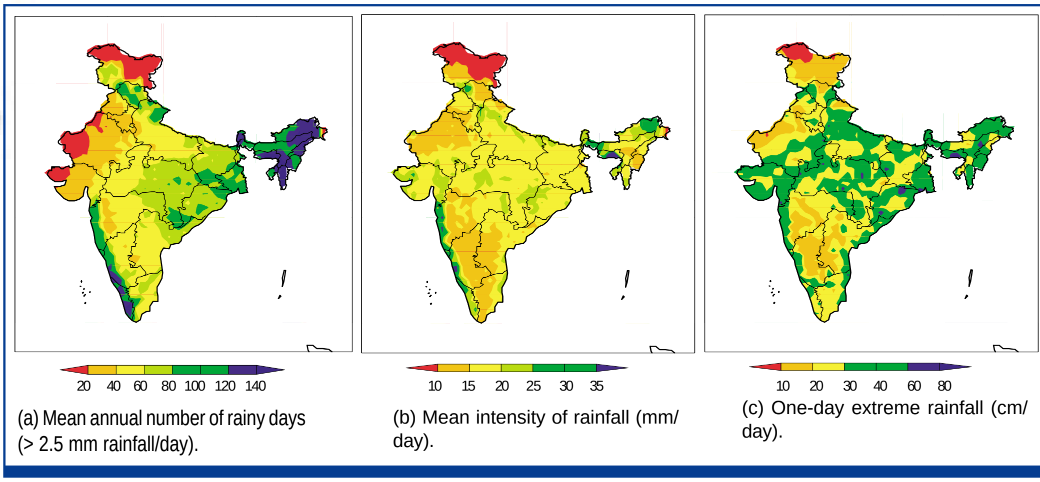
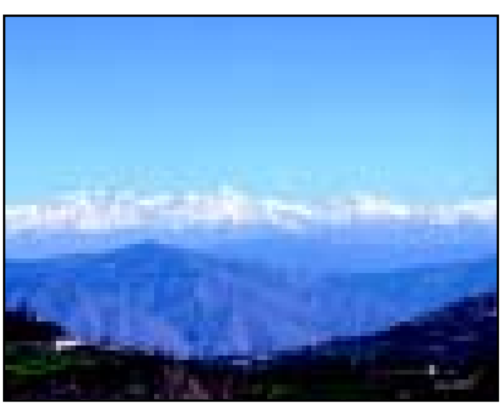


Figure 1.1: Indian rainfall profile.

January to July. During the winters, dry and cold air blowing from the northerly latitudes from a north-easterly direction prevails over the Indian region. Consequent to the intense heat of the summer months, the northern Indian landmass becomes hot and draws moist winds over the oceans causing a reversal of the winds over the region. This is called the summer or the south-west monsoon.

The four principal seasons—identified area:

- Winter—December, January and February.
- Pre-monsoon or summer—March, April and May.
- South-west monsoon—June, July, August and September.



The Himalayas in the north influence the Indian climate considerably.

- Post-monsoon or Northeast monsoon—October and November.

The cold weather season starts in early December. Clear skies, fine weather, light northerly winds, low humidity and temperatures, and large daytime variations of temperature are the normal features of the weather in India from December to February. The cold air mass extending from the Siberian region, influences the Indian subcontinent (at least all of the north and most of central India) during the winter months. The Himalayas obstruct some of the spreading cold air mass. The mean winter temperatures increase from north to south up to 17 °N, the decrease being sharp as one moves northwards in the north-western parts of the country. During January, the mean temperatures vary from 14 °C to 27°C. The mean daily minimum temperatures range from 22 °C in the extreme south, to 10 °C in the northern plains and 6 °C in Punjab. The rains during this season generally occur over the western Himalayas, the extreme north-eastern parts, Tamil Nadu and Kerala.

The mean daily temperatures begin to rise all over the country by the end of winter, and by April, the interior parts of the peninsula record mean daily temperatures of 30-35 °C. The central regions become warm with daytime maximum temperatures reaching about 40 °C at many locations. During this season

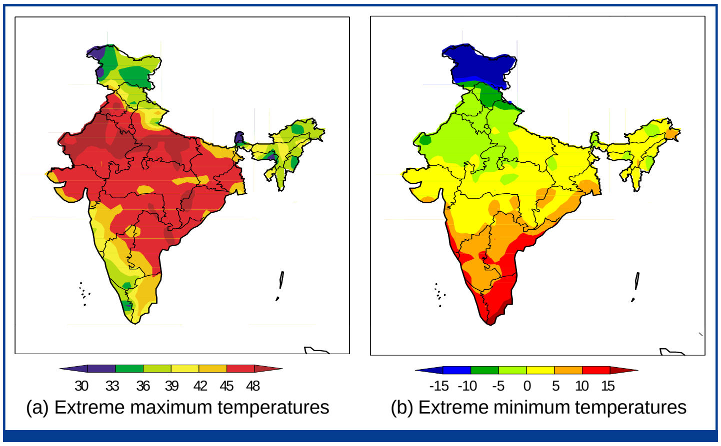


Figure 1.2: Indian temperature profiles (1951-1980).

stations in Gujarat, North Maharashtra, Rajasthan and North Madhya Pradesh are marked by high day-time and low night-time temperatures. At many locations in these regions, the range of the daytime maximum and night-time minimum temperatures exceeds 15 °C. In the north and north-west regions of the country, the maximum temperatures rise sharply, reaching values exceeding 45 °C by the end of May and early June, heralding the harsh summers (Figure 1.2). In the coastal areas of the country, land and sea breezes predominate due to the stronger temperature contrast between the land and the sea during this season.

Tropical cyclones, which are intense circulations of 200-300 km diameter, with winds blowing at velocities close to 150 km/hr form in the Bay of Bengal and the Arabian sea during this season. The storms generally move towards a north-westerly direction at first and later take a northerly or north-easterly path. Storms forming over the Bay of Bengal are more frequent than the ones originating over the Arabian Sea. About 2.3 storms form on an average during a year.

Thunderstorms associated with rain and sometimes hail are the predominant phenomena of this season. Over the dry and hot plains of north-west India dust storms (known locally as *andhis*), accompanied with strong dust-laden winds, occur frequently. Violent thunderstorms with strong winds and rain lasting for short durations also occur over the eastern and north-eastern regions in the states of Bihar, West Bengal and Assam. They are called norwesters because they generally approach a location from the northwest direction (locally they are known as *Kal Baisakhis* in the context of their season of occurrence).

The SW monsoon over India is the single most important feature of the Indian climate. Although it is spread over four months (June-September), its actual period at a specific place differs depending on the dates of its onset and withdrawal. The duration of the monsoon varies from less than 75 days as in West Rajasthan, to more than 120 days observed over the south-western regions of peninsular India. The rains during this season alone contribute to about 80 per cent of the annual rainfall of the country.

The SW monsoon normally sets in over the Kerala coast, the southern tip of the country, by 1 June, advances along the Konkan coast in early June and extends over the entire country by the end of July. On islands in the Bay of Bengal, the onset occurs about a week earlier. The onset of the monsoon over the country is one of the most spectacular meteorological events every year and is looked upon with great expectations by the people of India as it heralds a major rainy season and the beginning of sowing operations on a large scale. The SW monsoon rains

Tropical cyclones cause wide-spread devastation.

exhibit a striking regularity in their seasonal onset and distribution within the country, but are variable both within the season, and from one year to another. Global features like *El Nino*, northern hemispheric temperatures and snow cover over Eurasia are known to influence the year-to-year variability of monsoon performance. Within a season, the monsoon rainfall oscillates between active spells associated with widespread rains over most parts of the country and breaks with little rainfall activity over the plains and heavy rains across the foothills of the Himalayas. Heavy rainfall in the mountainous catchments under 'break' conditions leads to the occurrence of floods over the plains. Breaks are also associated with very uncomfortable weather due to high humidity and temperatures.

The Bay of Bengal during this season, is a source of cyclonic systems of low pressure called 'monsoon depressions'. They form in the northern part of the bay with an average frequency of about two to three per month and move in a northward or north-westward direction, bringing well-distributed rainfall over the central and northern parts of the country. The path taken by these depressions critically influence the distribution of rainfall over northern and central India.

Towards the latter half of September, the SW monsoon current becomes feeble and begins withdrawing from the north-western parts of India. By the end of September, it withdraws from almost all parts of the country and is slowly replaced by a northerly continental airflow. The retreating monsoon winds cause occasional showers along the east coast of Tamil Nadu, but decrease towards the interior.

The post-monsoon or north-east (NE) monsoon season is a transitional season, when the north-easterly airflow becomes established over the subcontinent. These winds produce the winter or NE monsoon rains over the southern tip of the country during the transitional period. Tropical cyclones that form in the Bay of Bengal and move in during this season cause heavy rainfall along their path. Many parts of Tamil Nadu and some parts of Andhra Pradesh and Karnataka receive rainfall during this season solely due to these storms. They can also cause widespread damage due to high-velocity winds and tidal waves in the coastal regions.

The day temperatures all over the country begin falling sharply. The mean temperatures over north-western India fall from about 38 °C in October, to 28 °C in November. This is accompanied by a decrease in humidity levels and clear skies over most parts of north and central India after mid-October.

GEOGRAPHY, LAND USE AND WATER RESOURCES

Water is the most critical component of life support systems. India shares about 16 per cent of the global population but it has only 4 per cent of the total freshwater resources. India is a land of many rivers. The 12 major rivers, spread over a catchment area of 252.8 million hectares (Mha), cover more than 75 per cent of the total area of the country. The rivers in India are classified as: the Himalayan, peninsular, coastal, and inland-drainage basin rivers. The Himalayan rivers are snow fed and maintain a high to medium rate of flow throughout the year. The heavy annual average rainfall levels in the Himalayan catchment areas further add to their rates of flow. During the summer monsoon months of June to September, the catchment areas are prone to flooding. The volume of the rain-fed peninsular rivers also increases during the monsoon. The coastal streams, especially those in the west, are short and episodic. The rivers of the inland system, centred in western Rajasthan, are few and sparse and frequently disappear altogether in years of poor rainfall. Most of the major Indian rivers flow through broad, shallow valleys and eventually drain into the Bay of Bengal.

The Ganges is the most prominent Indian river.

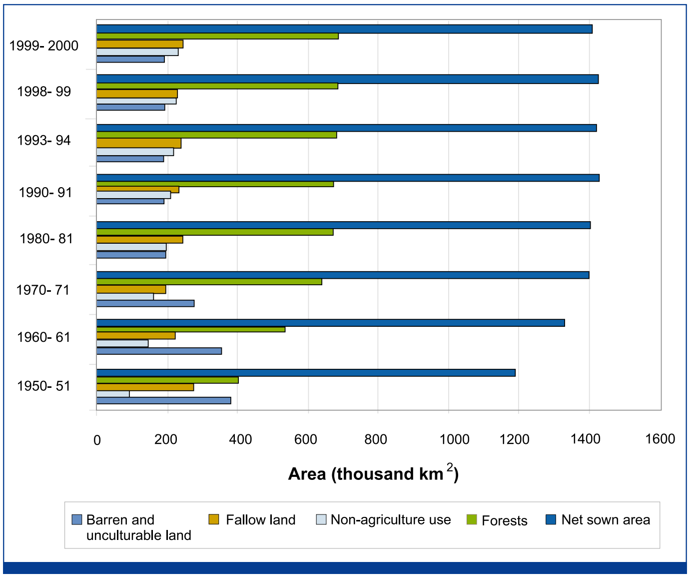


Figure 1.3: Indian land-use changes.
Source: Land Use Classification and Irrigated Area: 1998-1999, Ministry of Agriculture, Government of India.

Ground water is another major component of the total available water resources. In the coming years the ground water utilization is likely to increase manifold for the expansion of irrigated agriculture and to achieve national targets of food production. Although ground water is an annually replenishable resource, its availability is non-uniform in terms of space and time.

The land-use pattern is influenced by a variety of factors, such as population density, expanding urbanization, industrial growth, agriculture, grazing needs, irrigation demands, and natural calamities like floods and droughts. Despite these stresses, the area under forests has increased steadily due to proactive reforestation and afforestation programmes of the Government of India over the years, aimed at sustainable development. Presently, 23 per cent of the total land area is under forest and tree cover, while 44 per cent is net sown area (Figure 1.3). The remaining one-third is almost equally distributed between fallow land, non-agricultural land, and barren land.

The panorama of Indian forests ranges from evergreen tropical rain forests in the Andaman and Nicobar Islands, the Western Ghats, and the north-eastern states, to dry alpine scrub high in the Himalayas to the north. Between the two extremes, the country has semi-evergreen rain forests, deciduous monsoon forests, thorn forests, subtropical pine forests in the lower montane zone and temperate montane forests. The forests of India can be divided into 16 major types, comprising 221 sub-types. The area under forests as per land records was 6,83,100 km^2 in 1994 and 6,90,200 km^2 in 2000. However, the entire area recorded as 'forest' did not bear forest cover (as this includes grassland, wasteland and desert under the administrative control of the state forest departments). India's forest cover in 1994 was assessed in 1997 by the Forest Survey of India through satellite imagery interpretation at 6,33,397 km^2 (Figure 1.4), increasing to 6,75,538 km^2 for the year 2000 (as per the assessment conducted in 2001). An estimated 2.46 billion trees outside forests contributed an additional area of 81,472 km^2, making the total tree and forest cover at 23.03 per cent of country's geographic area in 2000.

The forests of India are a source of fuel and fodder for rural people, an industrial input for a growing economy, a habitat for thousands of plant and animal species, a sink for CO_2 emissions, and a protective cover for its soils. An effective Forest (Conservation)

A Sal forest in the central plains of India.

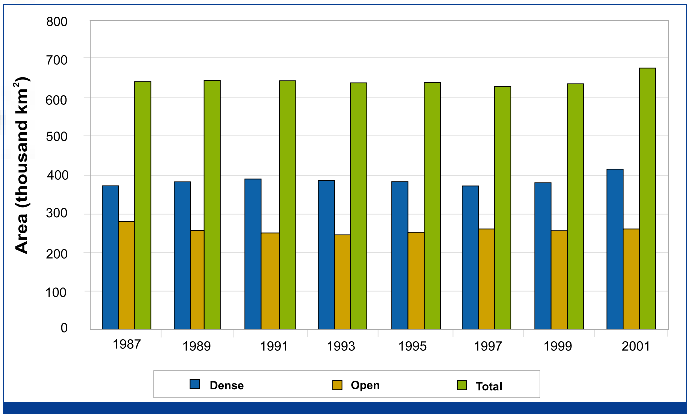


Figure 1.4: Indian forest cover assessments, 1987-2001.

Note: Mangroves are not covered in either dense or open forests during 1987-1997 but are included in total forest area. However they have been sub-classified into dense and open forests since 1999.

Source: Status of Forest Reports, 1987 to 2001, Ministry of Environment and Forests, Government of India.

Act, 1980, further strengthened in 1988, stipulating a massive afforestation programme, the establishment of reserves and re-vegetation of degraded lands through joint forest management and people's participation, helped India to conserve its forests and put a check on the diversion of forest land to non-forest uses. In spite of such measures, the average growing stock in India is 74 m^3/ha, much lower than the global average of 110 m^3/ha. Despite the various conservation acts, the forests themselves are degrading because of continued illegal felling, extraction of fuel-wood and non-timber products, invasion by weeds, and forest fires.

Planned afforestation programmes began in the late 1950s as a government policy for soil conservation, production of industrial raw material, fuel-wood, fodder, and increasing tree cover in urban areas. After the establishment of Forest Development Corporations in the states and the launching of Social Forestry Projects, large-scale afforestation activity began in 1979. While the Forest Corporations continued planting industrially important species after clear felling of the commercially less-valued forests, most of the plantations under social forestry were established outside forest reserves, along rail, road and canal sides, other government wastelands, and in private farmlands using short rotation species. The annual planting rates were about 10,000 km^2 (1980-1985), 17,800 km^2 (1985-1990) and about 15,000 km^2 after 1991.

A comparison of the forest cover of India between the years 1994 and 2000 shows a net increase in the forest cover by 42,141 km^2. Dense forest (>40% tree canopy cover) increased by 46,690 km^2 (excluding dense mangroves), mainly due to the enhancement of many open forest areas to the dense forest category. The area under mangroves declined by 265 km^2 during this period. However, the forest cover of India has been increasing steadily over the years due to various conservation- and climate-friendly policies of the government. This increase is despite the diversion of about 43,200 km^2 of forestland for non-forest purposes such as agriculture (26,200 km^2), for feeding our increasing population, and developmental activities such as river valley projects, industrialization, mining, and road construction. In 1999, the Food and Agricultural Organization's State of the World's Forests Report had acknowledged that India was the only developing country in the world where the forest cover was actually increasing.

Despite these policy-induced forest cover enhancements, uncontrolled grazing by domestic livestock in forest areas is perhaps one of the most important reasons for the degradation of forests in India, as it destroys the seedlings and young recruits, and in turn the regeneration process. It has been estimated that about 77.6 per cent of India's forests are affected by livestock grazing. The pressure of grazing has increased tremendously owing to the increasing cattle population.

Shifting cultivation, mostly practised in the north-eastern parts of India, is another factor responsible for the degradation of forests; this affected about 1.73 Mha during 1987-1997. About 53 per cent of forests in India are affected by fire; of these 8.9 per cent are frequent incidences of fires while occasional fires affect 44.2 per cent of the forest area in India. These results are not indicative of annual fires, but indicate

Figure 1.5: Physiographic zones of India.
Source: Status of Forest Report, 2001.

that the areas are definitely prone to heavy or light fires.

Almost 53.4 per cent of India's land area comprises arid and semi-arid regions (Figure 1.5). In these regions, cultivation is restricted to more productive but limited land, while a large animal population depends on native vegetation. The rains are erratic and often come in a few heavy storms of short duration resulting in high run-off, instead of replenishing the ground water. Protective vegetation cover is sparse and there is very little moisture for the most part of the year. India's arid zone is the most densely populated desert in the world. The growing pressure on the land due to the ever increasing population (both human and cattle) and the absence of any subsidiary occupation, compels people to cultivate the marginal lands and graze the dunes. There is severe wind erosion in areas that have bare soils and unconsolidated geological material, like sand. The area subjected to high wind erosion is about 59.2 Mha, which includes about 7.03 Mha of cold desert in Ladakh and Lahaul valleys. In western Rajasthan, the process of desertification is active in about 13.3 Mha. The Government of India is committed to the United

Nations Convention to Combat Desertification and provides financial support and guidance for the implementation of centrally-sponsored schemes such as the Desert Development Programme, Drought Prone Areas Programme, and the Integrated Watershed Projects in the country.

The wetlands in India are distributed in various ecological regions ranging from the cold and arid zone of Ladakh, through the wet Imphal in Manipur, and the warm and arid zone of Rajasthan-Gujarat to the tropical monsoon-influenced central India, and the wet humid zone of the southern peninsula. Recent remote sensing studies show that the total wetland area of India is 7.58 Mha; of this 5.3 Mha is natural wetland, whereas 2.26 Mha is man-made wetland.

The coastal areas of India accommodate about one-fourth of the country's population that depends to a large extent on marine resources. Nine of the Indian states, namely, Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal are situated along the long coastline. In addition, some of the Union Territories such as Pondicherry and Daman, and groups of islands including Andaman and Nicobar in the Bay of Bengal and Lakshadweep in the Arabian Sea, also constitute coastal ecosystems of great economic and ecological importance.

AGRICULTURE

India is an agrarian society, with nearly 64 per cent of the population dependent on agriculture, though the share of agriculture in the GDP has been continuously declining. Crop production in India takes place in almost all land class types, namely, dry, semi-dry, moist, sub humid, humid, fluvisols and gleysols. Agriculture will continue to be important in India's economy in the years to come as it helps to feed a growing population, employs a large labour force, and provides raw material to agro-based industries.

Given the physical and biogenetic diversity of the Indian subcontinent, a strategy of diversified and regionally differentiated agriculture is desirable for improving the economy and augmenting its resources. India is one of the few developing countries that has the potential to produce crops in almost all land class types. This is indeed a great policy challenge and opportunity; particularly so in an emerging environment which regards bio-diversity as nature's bounty and not as earlier, a constraint to technological progress.

Crop yield is a function of many factors, including climate, soil type and its nutrient status, management practices and other available inputs. Of these, climate plays an important role, probably more so in India where the majority of agriculture is dependent on the monsoon, and natural disasters such as droughts and floods are very frequent. Therefore, efficient crop planning requires a proper understanding of agro-climatic conditions. This calls for the collection, collation, analysis and interpretation of long-term weather parameters available for each region to identify the length of the possible cropping period, taking into consideration the availability of water.

With 329 Mha of geographical area, India presents a large number of complex agro-climatic situations. The Planning Commission of India has delineated 15 agro-climatic regions, which were proposed to form the basis for agricultural planning in the country. The 15 regions are: Western Himalayan, Eastern Himalayan, Lower Gangetic Plains, Middle Gangetic Plains, Upper Gangetic Plains, Trans-Gangetic Plains, Eastern Plateau and Hills, Central Plateau and Hills, Western Plateau and Hills, Southern Plateau and Hills, East Coast Plains and Hills, West Coast Plains and Ghat, Gujarat Plains and Hills, Western Dry, and the Islands region. The agro-climatic zone planning aims at the scientific management of regional resources to meet the food, fibre, fodder and fuel-wood needs without adversely affecting the status of natural resources and the environment. The Ninth Plan has reiterated that agricultural planning should follow the agro-climatic regions. This should now be done using satellite imagery to provide an up-to-date base for developmental projects. The database has been already created and preparations for satellite-based information systems are at a fairly advanced stage.

India has come a long way since the 1950s, from being a food-starved to a food-sufficient country. Food grain production has increased by over four-fold since the 1950s. Agriculture contributed 22.61 per cent to India's GDP in 2001-2002, while 68 per cent of the country's workforce is employed in this sector. The improvement in grain yield has been realized through the 'green revolution' in the 1960s, and later with improved agricultural practices and inputs. These include improved mechanized farming since the 1970s, increased net area under irrigation (31 Mha in 1970-1971; 53 Mha in 1994-1995; and 57 Mha in 1998-1999) and net sown area (119 Mha in 1950-1951 that has increased and almost saturated at 143 Mha over the past decade). The growth in total fertilizer consumption (2.6 Mt in 1970-1971; 13.6 Mt in 1994-1995; and 16.6 Mt in 2000-2001) and the availability and use of high-yielding variety seeds (area under these for different crops increased from 15.38 Mha in 1970-1971 to 72.11 Mha in 1995-1996), have contributed substantially to the increased grain yield. Despite the above improvements, agriculture in India is still heavily dependent upon the monsoon, indicating its vulnerability to climate change.

Agriculture has been accorded high priority under the different five-year plans. The conversion of cultivable wastelands into the other categories of land use, especially into cultivated land, took place in the first two decades after Independence. Net sown area has increased by 12 per cent during 1954-1994, while the intensity of farming (area sown more than once) has increased almost three-fold during the same period. India has made fair progress in developing her agriculture in the past five decades and is now almost self-sufficient in food grain production.

The majority of livestock rearing in India is in small holdings for sub-sustenance activities, where the animals are small in size and weight.

India has 13 per cent of the global livestock population, with still increasing growth rates. However, there is a decelerating trend in almost all species except buffalo, poultry, goats and pigs (Figure 1.6). The populations of draught animals have witnessed negative trend. Despite the low productivity and off-take rates, the contribution from animal husbandry and dairying was 5.9 per cent of the GDP in 2000-2001 at current prices. The Indian livestock sector employs 18 million people and acts as a storehouse of capital and an insurance against crop failure. The GDP from the livestock sub-sector has grown at 7.3 per cent per annum during 1981-1998, much faster than the 3.1 per cent growth of the crop sector. With production concentrated among small landholders, rearing livestock also help improve income distribution.

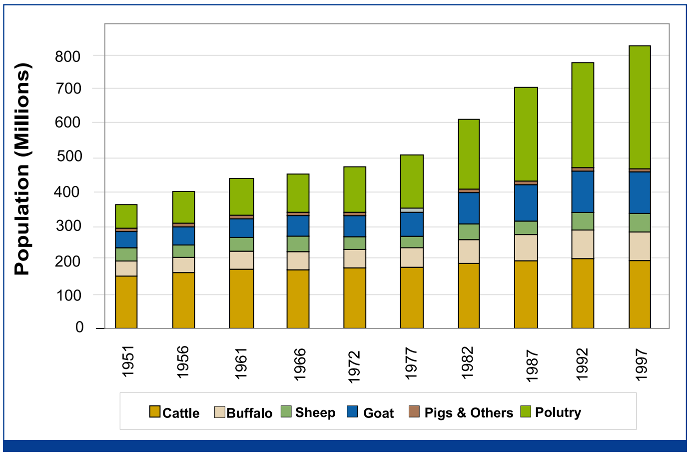


Figure 1.6: Changes in livestock population, 1951-1997

Source: Basic Animal Husbandry Statistics 2002, Ministry of Agriculture, Department of Animal Husbandry and Dairying, Government of India.

DEMOGRAPHIC PROFILE

Population levels and growth rates drive national consumption of energy and otherresources, and therefore GHG emissions. India's population has steadily risen over the years, crossing the one billion mark in 2000 and increasing annually by about 15 million since then. With a population of 846 million in 1991, 914 million in 1994, and 1027 million in 2001, India is the second most populous country in the world. The decadal population growth rate has, however, steadily declined from 24.8 per cent during 1961-1971 to 21.3 per cent during 1991-2001, and is targetted to further decline to 16.2 per cent during 2001-2011, due to various policies of the Government of India towards family welfare, education, health and the empowerment of women. This has resulted in reducing births by almost 40 million over the last 30 years.

India's population density is very high; the density of 264 persons/km^2 in 1991 increased to 324 persons/km^2 in 2001. 95 percent of India's districts have more than 50 persons/km^2, 80 per cent have above 100 persons/km^2 and 20 per cent have above 500 persons/km^2, as per the 1991 census (Figure 1.7). Almost all the coastal districts are very densely populated (above 500 persons/km^2), with over a 100 million people inhabiting them. This, coupled with low per capita incomes and low adaptive capacity of the majority of this population, renders them vulnerable to the impacts of climate change on coastal areas and fisheries.

India is steadily improving on many critical demographic indicators. The average life expectancy at birth has gone up from 32 years in 1951 to over 60 years today. The Total Fertility Rate (TFR) has declined during 1982-1992 resulting in the reduction of almost one child per woman. The TFR is projected to decline further from 3.13 during 1996-2001, to 2.52 during 2011-2016. The Infant Mortality Rate (IMR), a sensitive indicator of health status as well as of human development, has also declined considerably for both males and females. The average literacy rate has gone up from less than 20 per cent in 1951, to more than 65 per cent in 2001. The poverty level has gone down to 26 per cent of the total population in 2000 from 51.3 per cent during the 1970s. In spite of these achievements India continues to face the persistent challenge of population and poverty. Around 74 per cent of the population lives in rural areas, in about 5.5 lakh villages, many with poor communications and transport facilities. Reproductive health and basic health infrastructure require considerable strengthening, despite commendable achievements in the last 50 years. Nearly a 100 million people live in urban slums, with better but limited access to clean potable water, sanitation facilities, and health care services. In addition to this, there is the issue of a large-scale migration of people from rural to urban areas.

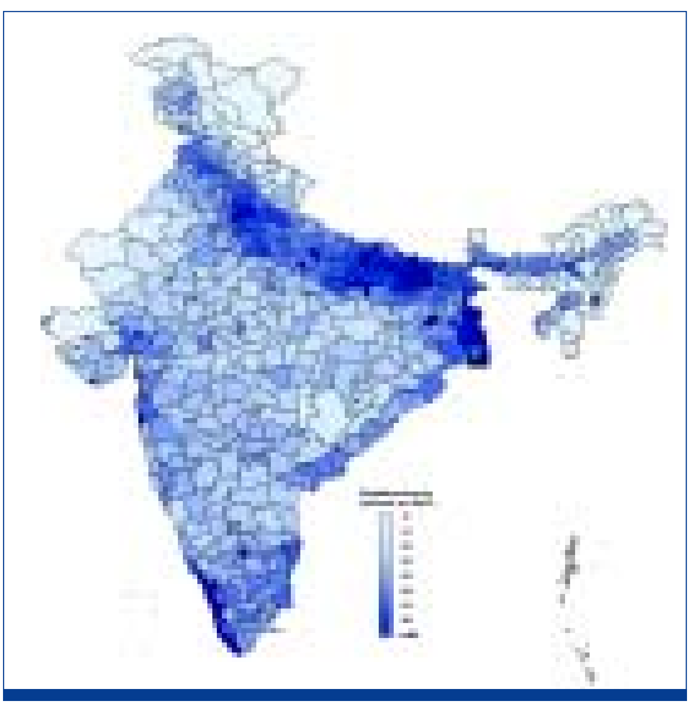


Figure 1.7: Indian population density, 1991.
Source: Census of India, 1991.

India is largely rural and the vast majority of the population continues to live in rural areas[2] (see footnote on the next page). The progress of urbanization has been relatively slow in India as compared to other developing countries. The urban population has increased from 19 per cent of the total population in 1965, to 28 per cent in 2000 (Figure 1.8). Nearly two-thirds of the urban population is concentrated in 317 Class-I cities (population of over 100,000), half of

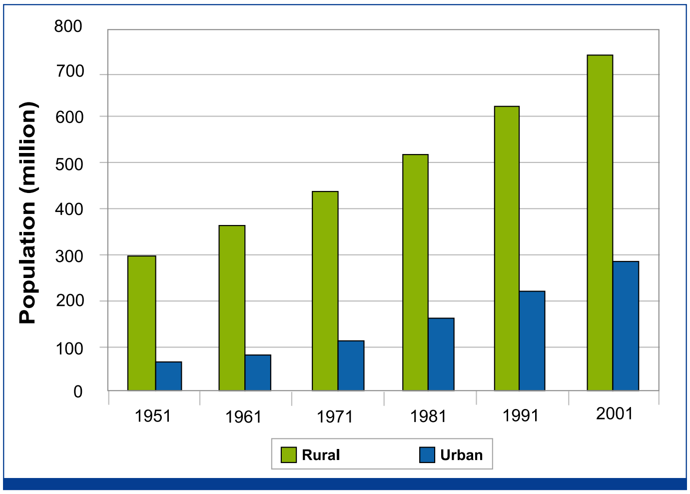


Figure 1.8: Rural-urban population profile of India.
Source: Census of India, 1991 and 2001.

which live in 23 metropolitan areas with populations exceeding one million each. The number of urban agglomerations/cities with populations of over a million, has increased from five in 1951, to 23 in 1991, and to 37 in 2001. This rapid increase in urban population has resulted in unplanned urban development, changed consumption patterns and increased demands for transport, energy, and other infrastructure. This may reflect rapid economic development and industrialization on one hand, but also high levels of energy consumption and emissions on the other.

Growing urbanization enhances GHG emissions.

India's population pyramid shows a broad base indicative of an expanding population. This structure includes a large number of children born each year. Even if the average number of children falls substantially in the future, the young age structure will generate continued growth for decades as a large number of them enter child-bearing age. Even if all Indians plan for two children per family, the population will continue to grow for the next 60 to 70 years. This will continue to build up a young age composition ' bulge'. This growing 'population bulge' of the younger and older population is pronounced in other Asian countries as well.

Households

India had more than 160 million households in 1994. Nearly three-fourths of these households lived in rural areas accounting for one-third of the total national energy consumption (NSSO 1993-1994; Census of India, 2001). Demographic changes have led to an appreciable rise in the total number of households in India with the urban share increasing faster than the rural one. There is also an increase in energy consuming appliances at all levels (Figure 1.9). However, this is an expected and desirable trend for a developing country where appliance-possession levels per 1000 households are still abysmally low in comparison to the developed and even many developing countries. For example, only 1.2 per cent urban households had a car in 1994, a figure that

[2] The conceptual unit for urban areas is a 'town', whereas for the rural areas it is a 'village.' The classification of an area as an urban unit in the Census of India (2001) is based on the following definition:

a All places declared by the state government under a statute as a municipality, corporation, cantonment board or notified town area committee, etc.

b All other places which simultaneously satisfy or are expected to satisfy the following criteria:

- A minimum population of 5,000;
- At least 75 per cent of the male working population engaged in non-agricultural economic pursuits; and
- A density of population of at least 400 per square kilometer (1,000 per square mile).

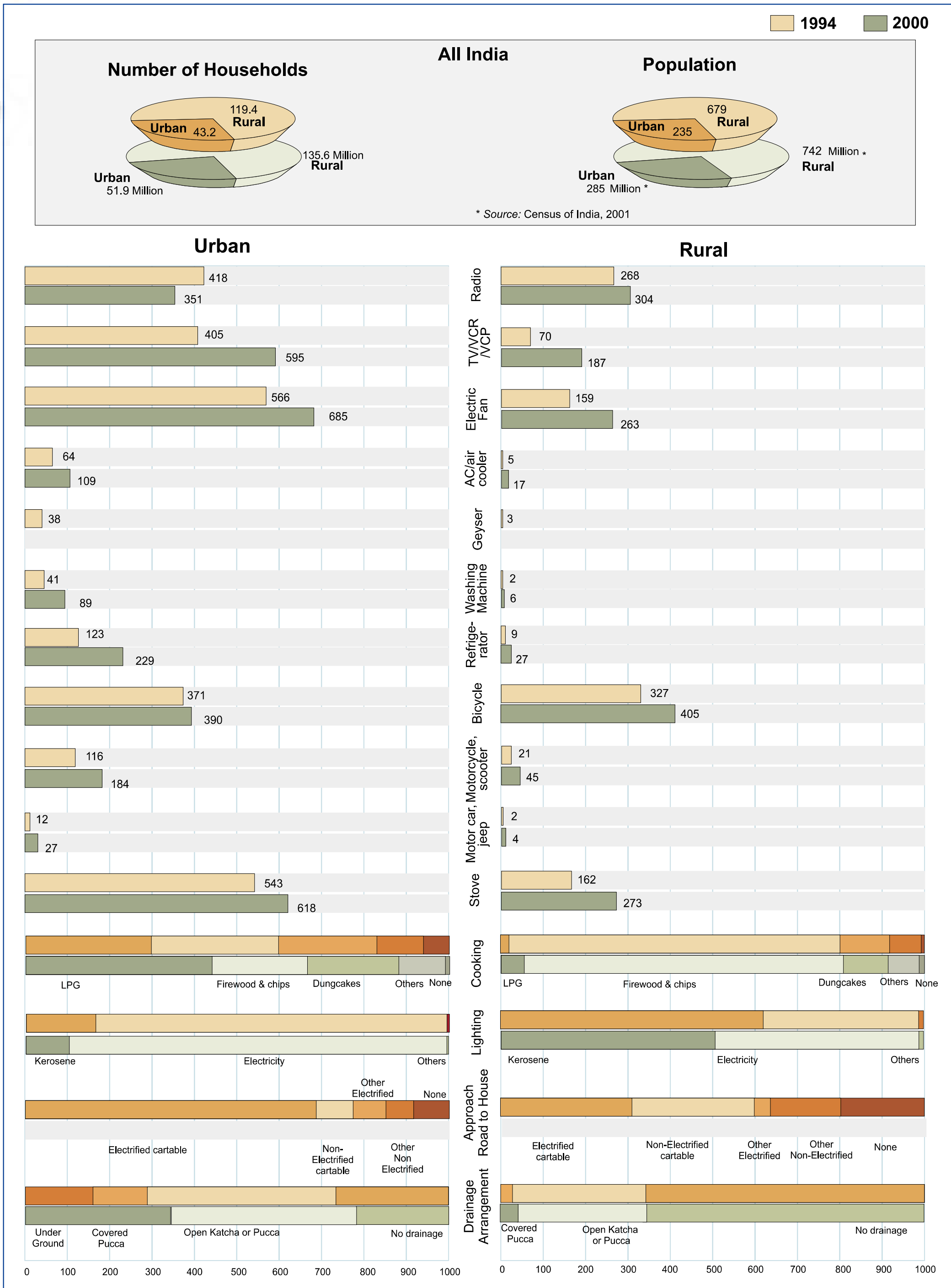


Figure 1.9: Indian household profile (number per 1000 households).

Source: National Sample Survey Organization, Fiftieth and Fifty-fifth round documents, Government of India.

increased to 2.7 per cent in 2000. Only 6.4 per cent urban households had at least one air-conditioner/ air-cooler in 1994 as compared to only 0.5 per cent in rural areas. In 1994 only 3.8 per cent urban households had geysers, 4.1 per cent had washing machines, 12.3 per cent had refrigerators, 29.6 per cent had liquid petroleum gas (LPG) for cooking, and 82.8 per cent had electricity for lighting. The corresponding numbers for the rural households are extremely low with only 1.9 per cent households having LPG for cooking, 2.1 per cent having motorcycles/ scooters, 15.9 per cent having electric fans, and 37.1 per cent having electricity for lighting in 1994. In the wake of rising incomes, the households at all socioeconomic levels are increasingly using energy consuming appliances. The related GHG emissions will therefore continue to rise, even though the energy efficiencies of the appliances are continually improving.

The share of *katcha* (mud huts), semi-*pucca* and *pucc*a (concrete) dwellings in total rural dwellings was 32 per cent, 36 per cent and 32 per cent, respectively in 1993. In the urban sector, about 75 per cent of households resided in *pucca* structures. As incomes rise, the demand for basic amenities such as housing, will increase. The construction sector has major linkages with the building material industry, since material accounts for more than half the construction costs in India. These include cement, steel, bricks, tiles, sand, aggregates, fixtures, fittings, paints, chemicals, construction equipment, petro-products, timber, mineral products, aluminium, glass and plastics. A rise in demand of these materials would influence future GHG emission trajectories for India.

GOVERNANCE PROFILE

India is the world's largest democracy; the legislature, the executive and the judiciary constitute the three building blocks of the Indian Constitution. The legislature enacts laws, the executive implements them, and the judiciary upholds them. The Indian Parliament consists of two houses, the Rajya Sabha (Upper House) and the Lok Sabha (Lower House). India has a unique system of federation with a manifest unitary character. The spheres and activities of the union and the states are clearly demarcated. The exhaustive union list and the state list placed in the seventh schedule of the Constitution distinctly outline the respective jurisdiction and authority of the union and the states. Some of the sectors belonging to environment and energy are listed in the concurrent list, wherein both the union and the state have concurrent jurisdiction to enact laws. The Constitution also devolves powers to the lower levels—'lower to the people'—through the institutions of *Panchayats* and *Nagar Palikas* (local municipal bodies), with a view to ensure administrative efficiency in concordance with the broader concept of good governance.

The government accords high priority to the environment. The MoEF is concerned with planning, promoting, coordinating and overseeing the implementation of environmental and forestry policies and programmes. It also serves as the nodal agency for international cooperation in the area of environment, including the subject of climate change. Environment ministries/ departments at the state level deal with state-specific environmental issues and concerns. Scientific and technical staff, as well as institutions and experts support environment administrations at union and state levels.

India has a strong and independent judiciary. Environmental issues have received a further boost through the judicial processes, which have recognized the citizen's right to a clean environment as a component of the right to life and liberty. Further, matters of public interest are articulated through vigilant media and the active NGO community.

Environmental governance

Environmental concerns are integral to the governance of India. Prior to the *United Nations Conference on Human Environment*, at Stockholm, the Government of India had established a *National Committee on Environmental Planning and Coordination* (NCEPC) under the aegis of the Department of Science and Technology. This commitment was a major step taken by India which was one of the pioneering nations in the world to amend its constitution to incorporate provisions to protect its environment. The constitutional provisions are backed by a number of laws—acts, rules and notifications. There are more than two dozen laws enacted to protect and safeguard India's environment. They cover all aspects of the environment—from pollution to conservation, from deforestation to nuclear waste disposal. Some of these laws are precursors to today's environmental movements.

There is a multiplicity of agencies involved in resource management in India and some overlaps in their responsibilities and jurisdiction are common. The allocation of resources to various sectors is directed by the Planning Commission working within the framework of the five-year plans. Environment management is guided at the central level by the MoEF and at state levels by the Departments of Environment. Natural resources (like water, forests and oceans) are managed by separate ministries and departments. Inter-ministerial coordination committees and working groups deal with the cooperation and conflict of interest issues. Indeed, in a large country this is perhaps inevitable. The implementation of government policies on resource use is directed by the multi-tier administrative structure. The administrative units at the central and state levels coordinate resource allocation and project implementation. However, the implementation of all programmes is done at the field level under the overall supervision of the district collector. Local bodies such as *Panchayat*s and city councils also have a stake in implementing various schemes in accordance with the instructions and directives of the collector, who is a civil servant. Several participatory management schemes dealing with environmental issues have been successfully carried out at the local level.

Most environmental legislation in India is based on active State intervention to preserve, protect and improve the environment. Some important acts related to the protection of environment are the Animal Welfare Act (1960), the Indian Wildlife (Protection) Act (1972), the Water Prevention and Control of Pollution Act (1974), the Forest (Conservation) Act (1980), the Air (Prevention and control of pollution) Act (1981), the Environment (Protection) Act (1986), the Public Liability Insurance Act (1991), and the Biological Diversity Act (2002).

ECONOMIC PROFILE

The GDP (at factor cost and constant prices) grew by 7.2 per cent in the financial year 1994. In the decade following the 1990s, the annual average GDP growth rate was 6.6 per cent making it one of the 10 fastest growing economies of the world. The key socioeconomic indicators for 1994 are presented in Table 1.1. Despite this rapid economic growth, the per capita GDP is one of the lowest, and it is a fact that

Table 1.1: National circumstances, 1994.

Criteria	1994
Population (M)	914
Area (Mkm^2)	3.28
GDP at Factor cost 1994-1995 (1993-1994 prices) Rs billion	8380
GDP at Factor cost 1994-1995 (1993-1994 prices) US$ billion	269
GDP per capita (1994 US$)	294
Share of industry in GDP (%)	27.1
Share of services in GDP (%)	42.5
Share of agriculture in GDP (%)	30.4
Land area used for agricultural purposes (Mkm^2)	1.423
Urban population as percentage of total population	26
Livestock population excluding poultry (M)	475
Forest area (Mkm^2)	0.64
Population below poverty line (%)	36
Life expectancy at birth (years)	61
Literacy rate (%)	57

Note: The monthly per capita poverty lines for rural and urban areas are defined as Rs 228 and Rs 305 respectively for 1994-1995.
Source: Economic survey 1995-1996 and 2000-2001. Economic Division, Ministry of Finance, Government of India.
Census of India, 1991 and 2001, Government of India.

one-fourth of its population of over one billion is still below the poverty line and that 44 per cent of the Indian population has an income below 1 US$/day. Its human development index is only at 0.571, compared to China (0.718) and to developed countries such as Germany (0.921), Japan (0.928) and the USA (0.934). The technology achievement index of India is at 0.201, which is comparable to China, but far below the developed countries (UNDP, 2001).

Social development depends to a great extent on economic development. For many decades, India followed a mixed economy model, where central planning coexisted with private enterprise. Agricultural activities, however, have rested almost entirely with private farmers. Industrial investment was sought to be controlled through industrial licensing until 1991.

In that year, a major programme of reforms was initiated under which industrial licensing was abolished and trade constraints relaxed, protection reduced and a greater emphasis was laid on the private sector.

GDP and its structure

The Indian economy has made enormous strides since independence in 1947, achieving self-sufficiency in food for a rising population, increasing the per capita GDP by over three-folds, reducing illiteracy and fertility rates, creating a strong and diversified industrial base, building up infrastructure, developing technological capabilities in sophisticated areas and establishing growing linkages with an integrated world economy.

The primary sector (particularly agriculture) remains the bedrock of the Indian economy, although its share in the total GDP has declined from over 50 per cent in the early 1950s to about 23 per cent in 2002-2003. At the same time the shares of manufacturing, transportation, banking and service sectors have doubled in the last 50 years. The growth of the Indian economy has also been accompanied by a change in its structure (Figure 1.10).

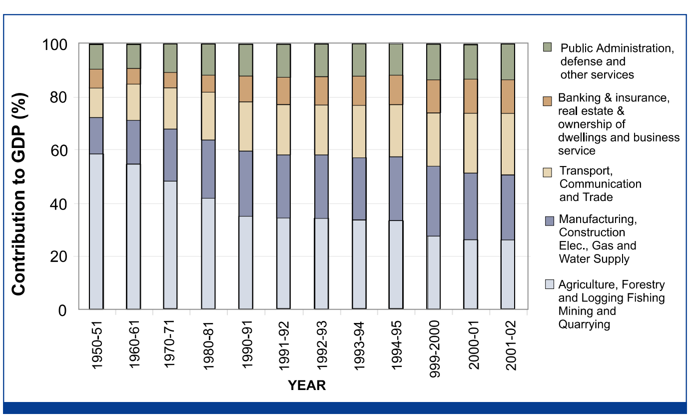


Figure 1.10: Sector-wise contribution to GDP (at factor cost).
Source: Economic Survey, 2003.

However, much remains to be achieved and the Government of India is committed to developmental targets that are even more ambitious than the United Nations Millennium Development Goals. The high incidence of poverty underlines the need for rapid economic development to create more remunerative employment opportunities, and to invest in social infrastructure such as health and education. Notwithstanding the climate-friendly orientation of the national policies, the developmental pathways to meet the basic needs and aspirations of a vast and growing population can only be expected to lead to increased GHG emissions in the future.

The Indian Budget

The national expenditure can be divided into two broad categories of 'plan' and 'non-plan', as well as 'developmental' and 'non-developmental'. The plan expenditure generally considers the plan outlays of the central government and concerns with the growth and investment in the economy, whereas the non-plan expenditure takes care of the recurring expenditures of the government and the economy. Furthermore, these are split into capital and revenue expenditures.

Non-plan expenditure has shown an increase during the past few years due to a significant rise in the share of defence expenditure and also a rise in interest payments, which is roughly about 15 per cent. Also, the non-plan expenditure on capital account shows an increase, since there has been an increase in the outlay for defence capital. The plan expenditure shows a gradual increase attributed to an increase in capital plan expenditure and central assistance to the states and Union Territories (UTs) among others. There has been a 22 per cent increase in the total expenditure, contributed to by about a 30 per cent increase in the plan expenditure and a 19 per cent increase in the non-plan expenditure.

The total expenditure as a percentage of the GDP has shown a gradual decrease since 1980. This may be due to the active participation of stakeholder organizations and the initiatives of NGOs. There has not been a marked decrease in the period 1991-2000, that may be attributed to the liberalization of the economy, wherein the government incurred a considerable amount of developmental expenditure.

Revenue receipts have two parts, namely Part A-revenue receipts and Part B-capital receipts. Part A explains the estimates of revenue receipts, which are grouped under two categories, namely: (a) tax revenue; and (b) non-tax revenue. Part B deals with capital receipts, which includes market loans, external assistance, small savings, government provident funds, special deposits and others. The Gross Tax Revenue (GTR) for the year 2002-2003 has shown an increase of 2,358 billion rupees from 1,983 billion rupees for the year 2000-2001. The rise in GTR for the year 2002-2003 can be attributed to the growth of the GDP, larger revenue generated from union excise duties, corporation tax and income tax. Similarly, the capital receipts have also shown increased trend of 1,652 billion rupees from 1,294 billion rupees for the year 2000-2001. The maximum gain is from short-, medium- and long-term loans. The total receipts account for 4,103 billion rupees for the year 2002-2003, as compared to 3,355 billion rupees for the year 2000-2001.

There has been an increase in total revenue receipts, which is around 19 per cent, contributed by the corresponding increase in the tax and non-tax revenues. The capital receipts have shown an increase of 28 per cent during the past three years. The total Receipts collected show an increase of 22 per cent over the past three years.

The tax revenue has increased by a considerable amount during the period 1991-2000. There has been a phenomenal increase in the capital as well as revenue receipts during the same period. However, the value of total receipts as a percentage of the GDP has increased only marginally, a reflection of the stability of the economy on the whole. The proportion of the tax revenue to the total revenue has been increasing quite noticeably. Also, there is a greater increase in the contribution of revenue receipts to total receipts, than to capital receipts from the period 1970-2001.

Poverty

Despite the growth of the population from 350 million in 1947, to more than a billion today, and despite the low level of economic development at the time of Independence, India has made significant progress in poverty reduction. The percentage of people below the poverty line has decreased significantly. Yet, large numbers of people continue to remain below the poverty line (Table 1.2).

The poverty line was originally defined in 1961, based on the income needed to provide adequate calorie intake, two pairs of clothing and a minimal amount of other essentials. This poverty line has been updated over the years to account for changes in prices. The estimates are based on large-scale sample surveys of household consumption carried out periodically by National Sample Survey Organization (NSSO).

Prior to Independence, India suffered from frequent, devastating famines and stagnation in growth. Therefore, the reduction of poverty and agricultural development have been the central themes of India's development strategy. Uplifting the poor and integrating them into the mainstream is a recurrent theme of India's five-year plans. Universal access to

Table 1.2: Percentage of people below the poverty line (All India).

Year	Rural	Urban	Total
1973-1974	56.44	49.01	54.88
1977-1978	53.07	45.24	51.32
1983	45.65	40.79	44.48
1987-1988	39.09	38.20	38.86
1993-1994	37.27	32.36	35.97
1999-2000	27.0	23.62	26.10

Source: Planning Commission, 2000.

education is enshrined in the Constitution. India has established a wide array of anti-poverty programme and much of India's thinking on poverty has been mainstreamed internationally. India has also successfully eliminated famines and severe epidemics. It has made progress in reducing poverty and in its social indicators, which at the time of Independence in 1947, was among the world's poorest. Its vibrant democracy and free press have been major factors in these achievements.

The incidence of poverty began to decline steadily since the mid-1970s that roughly coincided with a rise in the growth of the GDP and agriculture. Since 1980, India's trend of 5.8 per cent growth rate is the highest among large countries outside East Asia. Empirical analyses suggest that agricultural growth and human development were key factors in the decline in poverty across the country. However, the development strategy of the 1970s and 1980s, based on an extensive system of protection, regulation, expansion of public sector in the economy, and on worsening fiscal deficits in the 1980s, proved unsustainable. In 1991, a crisis in the balance of payments and the fiscal situation were met by stabilization and reforms that opened-up the economy, reduced the role of the public sector, and liberalized and strengthened the financial sector over the next few years. These policies generated a surprisingly quick recovery, and an unprecedented 7.7 per cent per annum average growth followed for three consecutive years. This led to an increase in productivity at the macroeconomic level and a booming private sector. During the 1990s, an agricultural growth of 3.3 per cent per annum was maintained that was about the same as in the 1980s, but much higher than the declining rate of population growth, estimated at about 1.6 per cent per annum.

Poverty is a global concern, and its eradication is considered integral to humanity's quest for sustainable development. The reduction of poverty in India is, therefore, vital for the attainment of national as well as international goals. Poverty eradication has been one of the major objectives of the development planning process.

The high incidence of poverty underlines the need for rapid economic development to create more remunerative employment opportunities and to invest in social infrastructure of health and education. These developmental priorities would enhance our energy consumption and therefore related GHG.

ENERGY PROFILE

The fact that energy, as an input to any activity, is one of the important pillars of the modern economy, makes the energy policy inseparable from the entire national development strategy. The entire fabric of the developmental policy contains the elements of energy strategy that are rarely out of line with similar policies in other economic sectors. Thus, the path traversed by the Indian energy policy can be viewed in the light of the overall developmental strategy adopted by India after Independence.

Rapid economic development is dependent upon expansion of critical infrastructure and growth in industrial base. Expansion of energy sector is a necessary condition for sustaining growth of the vibrant economy. Since important economic sectors such as petroleum, steel, cement, aluminium etc. are energy intensive, the consumption of energy is bound to increase with the development process. India is at present aiming at 8 per cent growth rate, its energy requirements are bound to increase manifold in the near future. Thus, increase in green house gas emissions is inevitable in near future. The growth of energy, electricity and Indian economy with respect to GDP has been shown in the Figure 1.11.

The energy use during the past five decades has expanded, with a shift from non-commercial to commercial energy. Among the commercial energy sources, the dominant source is coal, with a share of 47 per cent. The dominance of coal is because India is endowed with a significant coal reserve of about 221 Bt that is expected to last much longer than its oil and natural gas reserves. The share of petroleum and natural gas in the total commercial energy used in the country are 20 per cent and 11 per cent respectively. The total renewable energy consumption including biomass, amounts to about 30 per cent of the total energy consumption in India.

The consumption of commercial fuels (coal, oil, natural gas) for production of power and other uses

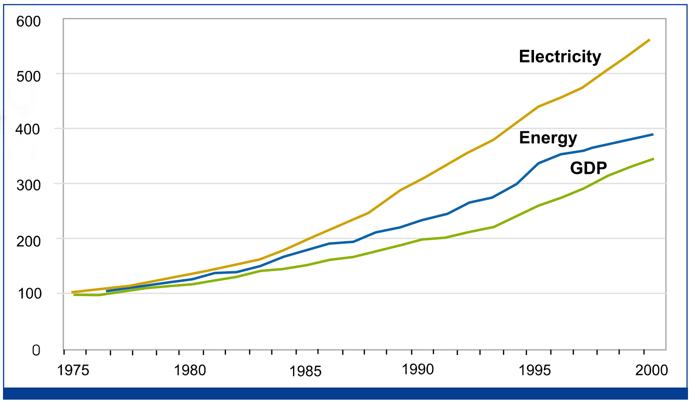


Figure 1.11: Growth of energy, electricity and the Indian economy.
Source: Economic Survey (1990-2003). Ministry of Finance, Government of India.

In order to meet the growing demand for oil, India imports around 70 per cent of total crude oil requirements. As regards natural gas, the Hydrocarbon Vision 2025 indicates that the gas reserves in India will decline by 16 billion m^3 by 2011-12, with reference to its consumption of 22.5 billion m^3 in 1998-99. Other than consumption of fossil fuel energy, about 90 per cent of the rural and 30 per cent of urban households in India consume a large quantity of traditional fuels or non-commercial energy such as fire wood, dung cake, chips etc. The total renewable energy consumption in India including biomass amounts to about 30 per cent of the total energy consumption in India. To meet the energy need of rural / remote areas, various initiatives have been taken up by GoI to provide electricity through locally available renewable energy sources such as solar, wind, biomass and small hydro schemes. These renewable resources are GHG free energy resources. However, as mentioned earlier, coal being abundant, cheap and locally available will be the mainstay of energy in India in near future to ensure energy security.

has been steadily rising over the years with domestically abundant coal continuing to be the dominant source. Coal meets 63 per cent of India's total energy requirements; followed by petroleum products (30%) and natural gas. Nearly 70 per cent of the power requirement in India is presently supplied by thermal power plants. The total coal reserves in India are 211 billion tons (MoC, 2000) and by current estimates these are enough to meet India's power needs for at least another 100 years. The commercial energy/power consumption in India is distributed among agriculture, industry, transport, domestic and other sectors. Out of these sectors, agriculture sector consumes both electricity as well as petroleum products mainly diesel; and the transport sector mainly uses petrol /diesel. For rail transport, both electricity and diesel are being used. CNG use has started for public road transport in some selected cities recently.

Primary energy supply

India has seen an expansion in the total energy use during the past five decades, with a shift from non-commercial to commercial sources of energy. Accordingly, the production of commercial sources of energy has increased significantly. Table 1.3 indicates the trends in production of various primary commercial energy resources.

Table 1.3: Trends in commercial energy production.

	Units	1960-1961	1970-1971	1980-1981	1990-1991	2001-2002
Coal	Mt	55.67	72.95	114.01	211.73	325.65
Lignite	Mt	0.05	3.39	4.80	14.07	24.30
Crude Oil	Mt	0.45	6.82	10.51	33.02	32.03
Natural Gas	BCM	-	1.44	2.35	17.90	29.69
Hydro Power	BkWh	7.84	25.25	46.54	71.66	82.8
Nuclear Power	BkWh	-	2.42	3.00	6.14	16.92
Wind Power	BkWh	-	-	-	0.03	1.70

Source: Tenth Five-Year Plan, Planning Commission, Government of India, 2002, pp 764.

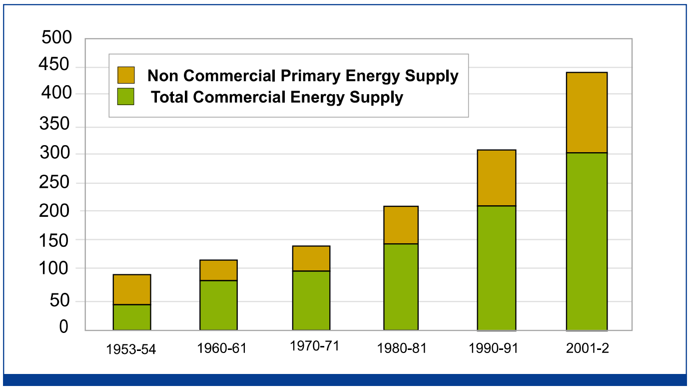


Figure 1.12: Decadal trend in TPES (Mtoe).
Source: Tenth Five-Year Plan, Planning Commission, Government of India, 2002, pp. 765.

The Total Primary Energy Supply (TPES) in India has grown at an annual rate of 3.4 per cent during 1953-2001, reaching a level of 437.7 Million Tonnes of Oil Equivalent (Mtoe) in the year 2001. Much of this growth has been contributed by commercial energy supply, which grew at 5.3 per cent per annum, in contrast to 1.6 per cent per annum growth experienced by non-commercial energy. As a result of this high growth, the share of commercial energy has increased from 28 per cent in 1953-1954 to 68 per cent in 2001-2002, with an associated decline in the share of non-commercial energy (Figure 1.12).

The period between 1953-1960 was one of high growth, with commercial energy supply growing at 6.5 per cent, but the growth slackened slightly during the next two decades only to pick up during 1980-1990. The growth in the past decade has also been impressive in view of several adverse international developments, such as the Asian financial crisis of 1997. The decade-wise growth rates in TPES, primary commercial energy supply and primary non-commercial energy supply, indicate a progressive increase in the commercialization of the Indian energy sector. However, despite reaching such high growth rates in TPES, the per capita energy consumption at 426 Kilograms per Oil Equivalent (Kgoe) in 2001 was one of the lowest in the world, though it has increased by a factor of 1.71 since 1953.

As stated earlier, coal remains the dominant fuel in our energy mix, with a share of 31 per cent, up from 26 per cent in 1953-1954 (Figures 1.13 and 1.14). Another fuel that has gained prominence is petroleum. From a share of just 2 per cent in 1953-1954 (as all petroleum was imported into India at that time), it has risen to about 27 per cent in 2001-2002. The share of natural gas has also increased from virtually nil to six per cent in 2001-02. The geological coal reserves, estimated at 221 Bt are expected to last the longest, given the current consumption and production trends. India is not expected to be self-sufficient in hydrocarbons. India has only 0.4 per cent of the world's proven reserves of crude oil, while the domestic crude oil consumption is estimated at 2.8 per cent of the world's consumption.

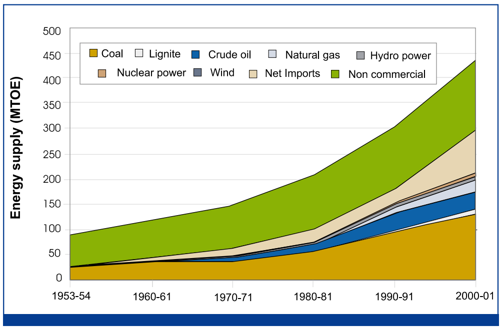


Figure 1.13 Trends in supply of primary energy (Mtoe)
Source: Tenth Five-Year Plan, Planning Commission, Government of India, 2002, pp. 765.

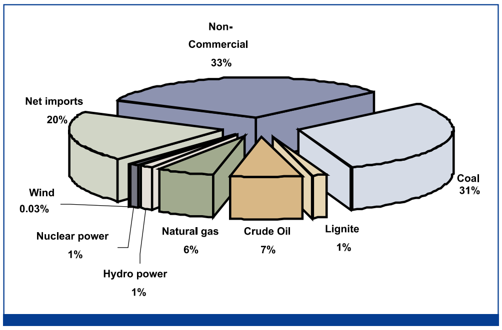


Figure 1.14 Share in primary energy supply, 2001-2002.
Source: Tenth Five-Year Plan, Planning Commission, Government of India, 2002.

Primary energy demand

The demand for petroleum products was estimated at 104.80 Mt during 2001-2002, excluding the liquid fuel requirement for power generation. During the first four years of the Ninth five-year plan (1997-2002), the consumption of petroleum products grew at 5.8 per cent. The consumption of petroleum products during 2001-2002 was 100.43 Mt thereby registering a growth of about 4.9 per cent during the Ninth Plan period, as against the target of 5.77 per cent (Planning Commission, 2002). The lower growth is mainly due to the slowdown in the economy, improvement of roads (including construction of bridges and bypasses) and the introduction of fuel-efficient vehicles. The demand for coal for domestic use has fallen drastically. At present Power Sector consumes nearly 70 per cent of the coal produced in the country. Demand for Coal from power sector is expected to rise further with the execution of on going capacity addition programme.

India is a developing country and three-quarters of the population lives in rural areas. Vast informal and traditional sectors with weak markets coexist with the growing formal and modern sectors. The traditional to modern transitional dynamics is expected to continue in the foreseeable future, further adding to the growth in energy demands. The future dynamics of energy consumption and technology selection in various sectors in India will thus determine their long-term implications for the energy and environmental concerns.

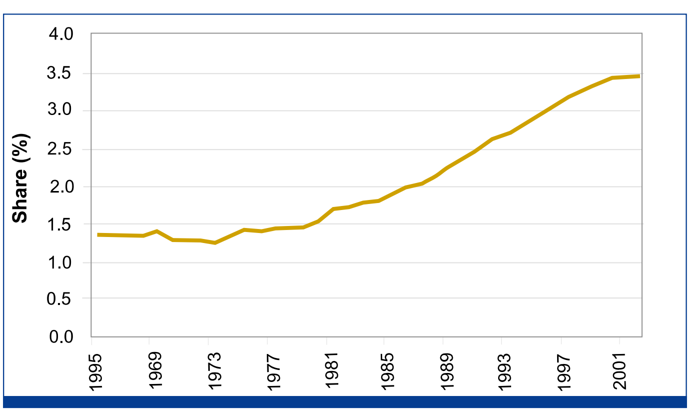


Figure 1.15: India's share in total world commercial energy consumption.
Source: CMIE, 2003.

Comparison with the world energy consumption

India ranks sixth in the world in terms of energy demand, accounting for 3.5 per cent of the world's commercial energy demand in 2001 (Figure 1.15). The world's total primary commercial energy supply (TPCES) grew at a compounded annual growth rate of 2.4 per cent over the period 1965-2002, with the Middle East and the Asia-Pacific regions displaying the highest growth rates. Within the Asia-Pacific region, India has exhibited one of the fastest growth rates in commercial energy supply. On the whole, the share of India in the total world commercial energy supply increased from 1.4 per cent in 1965 to 3.5 per cent in 2001.

However, despite achieving such high growth rates in energy consumption, the per capita energy consumption in India is still low according to global standards, and the energy efficiency of the GDP (PPP basis) is among the best. This holds true even if it is compared with other countries at a similar stage of development (Table 1.4).

POWER SECTOR

The Indian Constitution has included electricity in the concurrent list, which means that both the Centre and the States share the responsibility for this sector. The very first attempts at introducing legislation in this sector were made as early as 1887. However, these attempts were restricted to ensuring safety for personnel and property. The first legislation, i.e., the Indian Electricity Act, was passed only in 1910, followed by other acts. Until recently, the Indian Electricity Act (1910), the Electricity Supply Act (1948), and the Electricity Regulatory Commissions Act (1998), were the main regulations for the sector. The recent introduction of the Electricity Act (2003), has replaced the previous acts and consolidated them. Apart from the national level acts, each state is governed by its individual legislations. In 1991, the Policy on Private Participation in the Power Sector was drafted, which encouraged private

Table 1.4: Economy and energy.

	GDP per capita (PPP, US$), 2001	CO_2 emissions per capita (Metric tonnes), 1999	Electricity consumption per capita (kWh), 2000	GDP per unit of energy use (PPP, US$ per kg of oil equivalent), 2000	Traditional fuel consumption (as % of total energy use), 1997
India	2840	1.1	355	5.5	20.7
Developing countries	3850	1.9	810	4.6	16.7
OECD	23363	10.8	7336	4.9	3.3
High income	26989	12.4	8651	4.9	3.4
Middle income	5519	3.2	1391	4.0	7.3
Low income	2230	1.0	352	2.5	29.8
World	7376	3.8	2156	4.5	8.2

Source: United Nations Human Development Report, 2003.

participation in generation. At the same time, the Electricity Laws Amendment Act was passed, which gave more authority to the regional load despatch centres. The Electricity Regulation Act of 1998 initiated the setting up of the Central Electricity Regulatory Commission and also has provisions for setting up State Electricity Regulatory Commissions.

The growth in power generation capacity (Figure 1.16), which increased by almost seven-fold between 1970 and 2000, was accompanied by a greater diversity of technology mix. The capacity mix in 2000 included a substantial share of coal (61%) and 24 per cent share of hydro-based power. Gas-based power generation capacity gained momentum during 1990s and by the year 2000 its share in total installed capacity became eight per cent. Nuclear power has two per cent share and renewables around 1.5 per cent. In the past decade, generation capacity grew at 4.4 per cent annually, whereas electricity generation has grown at seven per cent due to improved plant utilization. As on March 2004, share of coal based thermal capacity is 58 per cent, gas/liquid based capacity is 11.5 per cent, hydro share is 26.3 per cent, nuclear share is 2.4 per cent and wind power is 1.8 per cent.

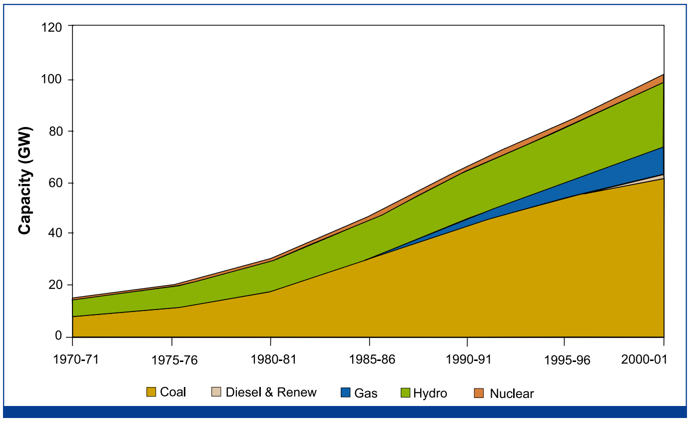


Figure 1.16: Power generation capacity.
Source: Sixteenth Power Survey, Ministry of Power, Government of India.

There has been significant growth in gas-fired power generation capacity in the past decade. With increase in private participation in the power sector, plants are being built in coastal areas near ports with terminals capable of handling liquefied natural gas (LNG). However, inland use of imported LNG remains expensive compared to coal, so natural gas is competitive in these regions only if transported by pipeline directly from the production field. Nuclear power from India's ten nuclear reactors contributes less than three per cent to total generation. There has been a considerable improvement in plant load factor of these plants during the past five years and they now operate around 80 per cent as compared to 60 per cent earlier.

Despite enhanced competition from other fuels, coal remains the mainstay of power generation. Domestic availability helps coal to retain a competitive advantage over imported fuels that have associated risks from fuel security and exchange rate uncertainties in the long run.

Many energy-intensive industries, such as aluminium, steel, and fertilizer have invested in on-site power generation, which is growing at an annual rate of eight per cent (CMIE Energy, 2001). Captive power generation has grown from about 1.6 GW in 1970 to almost 18 GW in 2002-2003, with almost half being coal based.

Renewables other than large hydro projects have a small share in the power generation capacity presently. However, India has a significant program to support renewable power. A number of facilitating measures have been enunciated in the Electricity Act 2003 to encourage the growth of renewable energy sector. Section 4 of the Act explicitly states that the Central Government shall, after consultation with the State Governments, prepare and notify a National Policy permitting stand alone systems (including those based on renewable sources of energy and non-conventional sources of energy) for rural areas.

TRANSPORT

Sustainable urban transport systems should be economically and socially equitable as well as efficient. When low-income groups do not have access to an affordable transportation system, this imposes hardships on them. Their time and energy is wasted in commuting, making them inefficient and thus trapping them in a vicious circle of poverty and inefficiency.

Managing the transport sector while minimizing externalities such as local pollution, congestion and GHG emissions is a major challenge. Rapid urbanization is now taking place in India. It is expected that more than 50 per cent of the population may reside in urban areas by 2025, a substantial increase from 28.9 per cent in 1999. An efficient transport system is a critical infrastructure requirement in cities for greater economic productivity and better quality of life.

Growing power, transport and construction sectors are main sources of CO_2 emissions.

Transport is a critical infrastructure for development. The sector accounts for a major share of consumption of petroleum products in India. Transport is responsible for an appreciable share of pollution, both local and global. Local pollutants are concentrated in the urban areas due to transport activities. The emission of global pollutants, especially of carbon dioxide (CO_2) from transport, is also a problem of increasing concern in the global environmental scenario.

The growth of registered motor vehicles in various cities of India is shown in Table 1.5. Metropolitan cities account for about one-third of the total vehicles in India. These trends indicate that the growth rate of vehicles could be high as the cities grow. As a number of towns in India are growing very rapidly, a very high level of vehicle growth can be expected in the future. Thus, while the growth of transport in metropolies slows down, it is growing faster in smaller cities. Some cities like Mumbai and Kolkata are very congested; Chandigarh is spread-out; Pune is also less congested. Delhi has a large fleet of buses and a good ratio of road length per person.

REFORMS AND GHG EMISSIONS

The momentous economy-wide reforms initiated in India in 1991 embraced a variety of sectors and activities that emit GHG as well as other pollutants. A significant area in this context is energy, including electricity, hydrocarbons and coal.

The Energy Conservation Act, 2001

The Energy Conservation Act, 2001 was enacted in September 2001 covering all the matters related to the efficient use of energy and its conservation. A Bureau of Energy Efficiency was set up to discharge the activities entrusted under the Act. The Bureau is expected to investigate the energy consumption norms for each energy-intensive industry and encourage the proper labelling of energy consumption indicators on every electrical appliance. The Bureau will also provide guidelines for energy conservation building codes and take measures to create awareness and disseminate information for the efficient use of energy and its conservation. It also aims to strengthen consultancy services in the field of energy conservation and develop testing and certification procedures and promote testing facilities for certification and for energy consumption of equipment and appliances. Various studies estimate that a potential of 23 per cent energy conservation exists in India. Enactment of Energy Conservation Act, 2001 would help in tapping this potential and thus, partially, offsetting the environmental impacts of new capacity addition.

Reforms in the electricity sector

The Ministry of power has initiated reforms in all aspects of power sector to make the sector viable. To encourage private sector participation with the objective of mobilizing additional resources for the power sector, the 'Private Power Policy' was announced in 1991.

The Electricity Regulatory Commission Act was promulgated in 1998 for setting up independent regulatory bodies, both at the central and the state level with an important function of looking into all aspects of tariff fixation and matters incidental thereto to make the sector viable.

Renovation and modernization (R&M), distribution reforms and GHG emissions

To augment T&D networks, system improvements, R&M of old stations for improving efficiency to make investment in energy conservation and environment performance schemes, concerted efforts are on for quite some time at various levels within the system. Reforms in R&M of old thermal power stations will result in improvement in efficiency, that is availability

Table 1.5: Total number of registered motor vehicles in India in 1951-2002.

(in thousands)

Year as on 31st March	All vehicles	Two wheelers	Cars, jeeps and taxis	Buses	Goods Vehicles	Others*
1951	306	27	159	34	82	4
1956	426	41	203	47	119	16
1961	665	88	310	57	168	42
1966	1099	226	456	73	259	85
1971	1865	576	682	94	343	170
1976	2700	1057	779	115	351	398
1981	5391	2618	1160	162	554	897
1986	10577	6245	1780	227	863	1462
1991	21374	14200	2954	331	1356	2533
1996	33786	23252	4204	449	2031	3850
1997	37332	25729	4672	484	2343	4104
1998	41368	28642	5138	538 @	2536	4514
1999	44875	31328	5556	540 @	2554	4897
2000 (R)	48857	34118	6143	562 @	2715	5319
2001 (P)	54991	38556	7058	634 @	2948	5795
2002 (P)	58863	41478	7571	669 @	3045	6100

*Others include tractors, trailors, three wheelers (passenger vehicles) and other miscellaneous vehicles which are not separately classified.
@ : Includes omni buses; (P) : Provisional; (R) : Revised.
Source: Motor Transport Statistics 2001-2002, Ministry of Road Transport and Highways.

of additional power with the same amount of coal burnt and, hence, lower greenhouse gas emissions. Similarly, reduction in technical losses will result in availability of extra power in the grid thereby partially offsetting the new power capacity to be added.

The Electricity Act, 2003

The Government of India has recently enacted the Electricity Act, 2003. The Act seeks to promote competition in the electricity sector in India by decoupling the generation, transmission, distribution and supply of electricity. The Act also envisages the preparation of a National Electricity Policy (including tariff) for the development of the power system based on the optimal utilization of natural resources. In consonance with this policy, the central electricity authority will prepare the National Electricity Plan once every five years.

The Act has de-licensed the generation of electricity in India. Clause (7) of the Act states that 'any generating company may establish, operate, and maintain a station without obtaining a license under this Act if it complies with the technical standards relating to the connectivity with the Grid'.

The Act has also heralded a move away from the Single Buyer model that was followed during the 1990s. Under this model, private power producers were allowed to sell power to SEBs only. However, the financial difficulties faced by the SEBs proved to be a major constraint for private participation. Under the new Act, the generator and the consumer can individually negotiate the power purchase and use the common access transmission and distribution system to meet the contractual obligations.

T&D reforms are important components of APDRP.

Thus, the Electricity Act, 2003 maintains the trend in electricity reforms witnessed the world over by exposing the generation and the supply side of the market to competition, but placing transmission and distribution sections under incentive regulation.

The Act has made the tariff policy one of the cornerstones of the regulatory process. Under the Act, either the state or the central regulatory commission is required to play an important role in tariff setting by the natural monopoly segments of the electricity supply chain, and ensure that such tariff is set through a transparent process of bidding in accordance with the guidelines issued by the central government. The Ministry of Power has recently come out with a discussion paper on the tariff policy. According to the paper, the tariff has to take into account the objectives of: (a) promotion of efficiency; (b) introduction of competition and creating enabling environment for the same; (c) rationalization of electricity tariff; (d) protection of consumer interests; and (e) transparency in subsidy administration (MoP, 2003).

Reforms in the hydrocarbons sector

India imported 77 per cent of her total petroleum consumption in 2001-2002 which required substantial funds. The domestic production failed to keep pace with the domestic requirement, forcing India to import more crude oil and petroleum products. The net imports of both crude oil and petroleum products declined to 32 per cent of total consumption in 1984-1985 from the high of 76 per cent in 1980-1981 but has risen steadily thereafter to reach 77 per cent in 2001-2002 (figure 1.17).

Few attempts at reforms were taken in the 1980s, when the upstream sector was opened for private participation in order to attract private capital and technology to boost indigenous oil production. Economy-wide reforms initiated in 1991 opened up the middle stream refining also for the private sector. The New Exploration and Licensing Policy (NELP) was launched in 1997 and the new format of competitive bidding and relinquishment of blocks by national oil companies made this policy an immediate

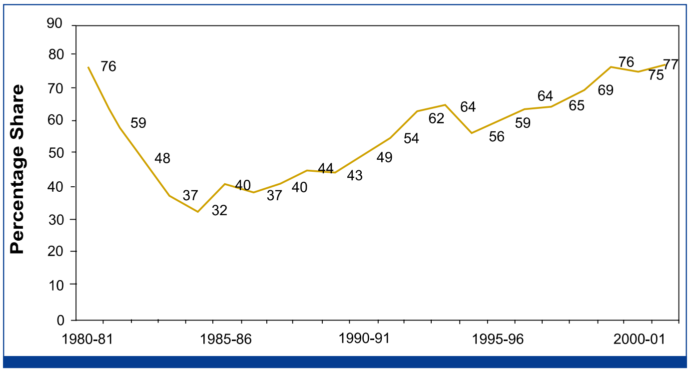


Figure 1.17: Share of petroleum imports in total consumption.

Source: Indian Petroleum and Natural Gas Statistics, 2003, MoPNG, Government of India.

success. Presently, NELP is due for its fourth round and, until now, a 100 blocks have been awarded to both public and private sector companies.

The government remained in control of the hydrocarbons sector in the form of the Administered Pricing Mechanism (APM). Various pool accounts ensured that the oil companies got a fixed return on their investments and the consumers got stable prices. However, mounting concerns about the inefficiency in the sector, the ever-increasing burden of subsidies and crude oil import bills, and sufficient refinery capacity in India propelled the government in 1997 to prepare a road map for dismantling the APM with a step-wise approach, reaching a completely free oil market by 2002. The prices of industrial fuels such as naphtha, fuel oil, bitumen and lubricants, were freed and the national oil companies were allowed to compete in this segment. The last step in dismantling the APM was taken in April 2002, when the Annual Budget 2002-2003 formally announced the move to market-based pricing and, since then, the oil companies, in consultation with the government, have been revising the prices fortnightly in line with the international trend.

Petroleum product pipeline policy

The government also announced a new petroleum product pipeline policy on a common carrier principle. The policy promotes the product pipelines originating from refineries, pipelines dedicated for supplying products to particular consumers, and pipelines originating from ports. The policy would reduce road and rail transport and enhance the supply of cleaner fuels and, hence, would reduce emissions of GHG and local pollutants.

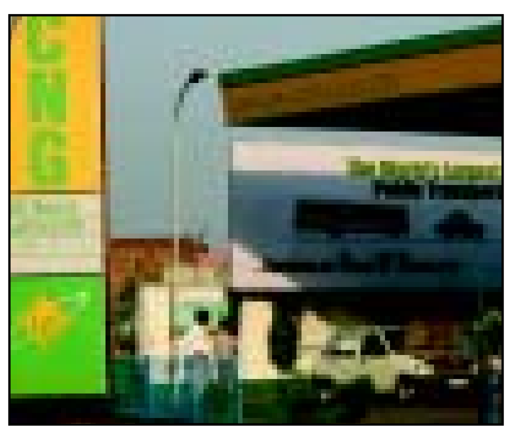
Auto Fuel Policy

The government announced the Auto Fuel Policy in 2003 to address the issues of vehicular emissions, vehicular technologies and the provision of cleaner auto fuels in a cost-efficient manner, while ensuring the security of fuel supply. These measures would result in the efficient combustion of fossil fuels in the road transport sector resulting in reduced GHG emissions. Transport sector emissions from Delhi are an interesting case in point, where the fuel switch to Compressed Natural Gas (CNG) from diesel in public vehicles has reduced CO_2 emissions. Apart from Delhi, CNG in respect of public passenger transport, has also been introduced in Mumbai.

Reforms in the coal sector

Towards reforming the coal sector, the government has recently constituted the Expenditure Reforms Commission (ERC). The major recommendations of the commission are:

- Remove all restrictions on the entry of the private sector in exploration and production of coal by amending the Coal Mines Nationalization Act, 1973.



Delhi has world's largest CNG-based public transport fleet.

- Amend the Coal Bearing Areas (Acquisition and Development) Act, 1957 and set up an independent regulatory body to allow for a level playing field to the private sector.
- Restructure the industry by doing away with the holding company (CIL) and Coal Controller, among other things.
- Amend the Coal Mines (Conservation and Development) Act, 1974, to place responsibility on both public and private sectors for scientific mining, conservation, safety and health, protection of environment, etc.
- Permit states to develop lignite resources outside the command areas of the Neyveli Lignite Corporation.
- Reorient the overall strategy to take into consideration the role of coal in energy security.

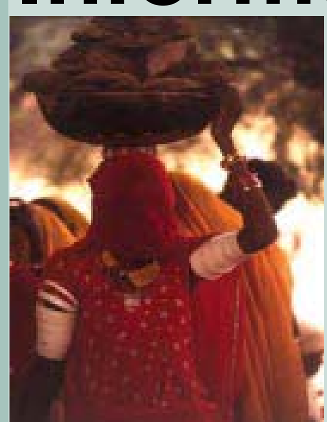
Prior to 1 January 2000, the central government was empowered under the Colliery Control Order, 1945, to fix the grade-wise and colliery-wise prices of coal. However, following the Colliery Control Order, 2000, the prices for all grades of coking and non-coking coal have been deregulated. The current basic price of coal varies from Rs 1,450 per tonne to Rs 250 per tonne for different grades.

INDIA'S COMMITMENT TO CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT

India accords great importance to climate change and her commitment to UNFCCC is reflected in the various national initiatives for sustainable development and climate change. As a commitment to the UNFCCC, India recently hosted the COP-8 at New Delhi. India has reasons to be concerned about the adverse impacts of climate change, since the vast population depend on climate sensitive sectors. The Government of India makes investments for the promotion of research and development on a continuous basis in diverse areas of the environment, including climate change. Environmental protection and sustainable development have emerged as key national priorities and are manifested in India's approach to socioeconomic development and poverty eradication.

Chapter 2

GHG Inventory Information



GHG Inventory Information

Chapter 2

The UNFCCC was adopted in 1992, in recognition of the concern that food security and economic development in the future may be adversely affected as a result of the discernible change observed in the climate since pre-industrial times. This change is mainly attributed to the continuously increasing concentration of GHGs in the atmosphere resulting from anthropogenic activities[1]. Therefore, central to any climate change study is the assessment of GHG inventory that identifies and quantifies a country's primary anthropogenic sources and sinks of GHGs.

The UNFCCC stipulates that each party to the convention should develop, periodically update, publish and make available to the Conference of Parties, a national inventory of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol, using comparable methodologies. The Convention also notes that the largest share of historical and current global emissions of GHGs has originated in developed countries and that the share of the global emissions originating in developing countries will grow to meet their social and developmental needs.

India has ratified the Convention in November 1993. As a non-Annex 1 nation under the Convention, the inventory information to be provided by India is according to the guidelines stipulated for Parties not included in Annex I to the UNFCCC. In this chapter, the information on India's GHG emissions by sources and removals by sinks for the base year 1994, is presented to the extent India's capacities permit, and is in accordance with the Articles 4.1a and 12.1a of the Convention. For a transparent and comparable emission inventory, the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1996) has been used in the present exercise. The sources from which the emissions have been estimated include energy, industrial processes, agriculture, land use, land-use change and forestry and waste. The gases covered are CO_2, methane (CH_4) and nitrous oxide (N_2O).

The rigour of any emission inventory relies on the quality of its activity data, the emission coefficients and inventory methodologies used. In the present inventory assessment, the authenticity of data is ensured by sourcing the primary activity data for various sectors from reports of the concerned government ministries, such as the Ministry of Coal, Oil and Natural Gas, Coal Mining, Road Transport and Highways, Heavy Industries and Public Enterprises, Railways, Civil Aviation, Agriculture, Steel, Science and Technology, and others (see References). Activity data, wherever possible have been cross - verified from multiple sources including, government documents, publications of industry associations and research institutions of repute, and in some cases, directly from the manufacturers. An important contribution of this national communications exercise is the estimation of indigenous emission coefficients in several key sectors through direct field measurements using rigorous scientific methodologies. The inventory assessment has contributed to the accuracy and reliability of the GHG budget estimates reported here.

For estimating GHG inventories, the IPCC (1996 Guidelines) Tier-I, II and III approaches were used. The choice of the approach for a sector, depended on the quality and availability of activity data and emission coefficient as required by each approach. For example, in the case of coal consumption in the energy sector, Tier-II approach was applied, wherein

[1] Since 1750, globally, concentration of CO_2, CH_4 and N_2O have increased by 31,151 and 17 % respectively (IPCC, 2001a).

fuel consumption data at sub-sectoral levels were used along with measured emission coefficients for different grades of domestic coal. Alternatively, for petroleum products combustion, the Tier-I approach was employed since the default emission coefficients for these fuels are fairly accurate due to consistent quality of these fuels across the globe. In the case of methane emissions from enteric fermentation from animals, a Tier-II approach was used, whereby the cattle were segregated into dairy and non-dairy segments and the emission coefficients were estimated for each age group.

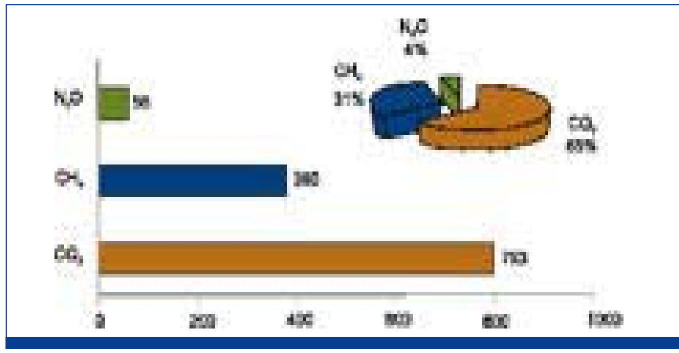


Figure 2.1: Relative emissions of GHGs from India in 1994.

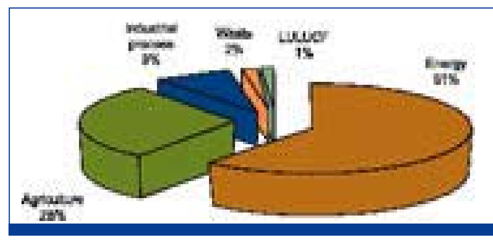


Figure 2.2: Percentage contribution of different sectors to the total GHG emissions.

Inventory estimates are inherently uncertain and are high due to the multiplicative effect of the uncertainties associated with the emission coefficient and activity data. The uncertainty in emission coefficient estimates arises from measurement inaccuracies and variable background conditions. In case of activity data, the key factors contributing to uncertainty are the aggregation errors, incompleteness of data and mismatch of data definitions. In developing countries, the accuracies are also added by the paucity of data for informal, traditional, and unrecognized sectors. Considerable uncertainties thus would exist in the present emission estimates of GHGs from various sectors.

INDIA'S GREENHOUSE GAS INVENTORY FOR THE YEAR 1994 — A SUMMARY

In 1994, the aggregate emissions from the anthropogenic activities in India amounted to 7,93,490 Gg of CO_2; 18,083 Gg of CH_4; and 178 Gg of N_2O. In terms of CO_2 equivalent[2] (Tg-CO_2 eq.), these emissions amounted to 12,28,540 Gg. The per capita CO_2 emissions were 0.87 t-CO_2 in 1994, four per cent of the US per capita CO_2 emissions in 1994, eight per cent of Germany, nine per cent of UK, 10 per cent of Japan and 23 per cent of the global average. CO_2 emissions contributed, 65 per cent of total GHGs; CH_4 contributed 31 per cent and four per cent of emissions were contributed by N_2O (Figure 2.1). On a sectoral basis (Figure 2.2), 7,43,820 Gg CO_2-eq. of GHGs were emitted from energy sector (61 per cent); 3,44,485 Gg of CO_2-eq. emissions came from the agriculture sector (28 per cent); 1,02,710 Gg of CO_2-eq. were contributed by the industrial processes (8 per cent); 23,233 Gg from waste disposal (2 per cent) activities and 14,292 Gg were generated from land use, land-use change and forestry sector (1 per cent). Table 2.1 summarizes the GHG emissions from various sectors by sources and removals by sinks for India for the base year 1994.

7,43,820 Gg of CO_2-eq GHGs, i.e., 61 per cent of the total GHG, emitted from all energy activities were mainly from the combustion of fossil fuels. Among

[2] Each of the GHGs has a unique average atmospheric lifetime over which it is an effective climate-forcing agent. Global warming potential (GWP) indexed multipliers have been established to calculate a longevity equivalency with carbon dioxide taken as unity. The GWP of methane and nitrous oxide are 21 and 310, respectively (IPCC, WKI, 1996). By applying unique GWP multipliers to the annual emissions of each gas, an annual CO_2 equivalency may be summed that represents the total GWP of all climate-forcing gases considered.

Table 2.1: India's initial national greenhouse gas inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol for the base year 1994.

GHG source and sink categories (Gg per year)	CO_2 emissions	CO_2 removals	CH_4	N_2O	CO_2 eq. emissions*
Total (Net) National Emission	**817023**	**23533**	**18083**	**178**	**1228540**
1. All Energy	**679470**		**2896**	**11.4**	**743820**
Fuel combustion					
Energy and transformation industries	353518			4.9	355037
Industry	149806			2.8	150674
Transport	79880		9	0.7	80286
Commercial/institutional	20509			0.2	20571
Residential	43794			0.4	43918
All other sectors	31963			0.4	32087
Biomass burnt for energy			1636	2.0	34976
Fugitive Fuel Emission					
Oil and natural gas system			601		12621
Coal mining			650		13650
2. Industrial Processes	**99878**		**2**	**9**	**102710**
3. Agriculture			**14175**	**151**	**344485**
Enteric Fermentation			8972		188412
Manure Management			946	1	20176
Rice Cultivation			4090		85890
Agricultural crop residue			167	4	4747
Emission from Soils				146	45260
4. Land use, Land-use change and Forestry*	**37675**	**23533**	**6.5**	**0.04**	**14292**
Changes in forest and other woody biomass stock		14252			(14252)
Forest and grassland conversion	17987				17987
Trace gases from biomass burning			6.5	0.04	150
Uptake from abandonment of managed lands		9281			(9281)
Emissions and removals from soils	19688				19688
5. Other sources as appropriate and to the extent possible					
5a. Waste			**1003**	**7**	**23233**
Municipal solid waste disposal			582		12222
Domestic waste water			359		7539
Industrial waste water			62		1302
Human sewage				7	2170
5b. Emissions from Bunker fuels #	**3373**				**3373**
Aviation	2880				2880
Navigation	493				493

Not counted in the national totals.
*Converted by using GWP indexed multipliers of 21 and 310 for converting CH_4 and N_2O respectively.

the fossil fuels, coal combustion had a dominant share of emissions, amounting to about 4,75,530 Gg of CO_2-eq GHGs i.e., about 64 per cent of all energy emissions. The non-CO_2 emissions in this category are from biomass burning and fugitive emissions released from coal mining and handling of oil and natural gas systems. An analysis of the distribution of the total CO_2-eq emissions across all the sub components of all energy activities (Figure 2.4) indicates that the major emitters were energy and transformation industries (47 per cent) constituting mainly electric power generation, industry (20 per cent) and the transport sector (11 per cent).

Of the total GHGs released in 1994, eight percent i.e., 1,02,710 Gg CO_2-eq were from the industrial process sector. These include CO_2, CH_4 and N_2O emissions from production processes of chemicals, metals, minerals, cement, lime, soda ash, ammonia, nitric acid, calcium carbide, iron and steel, ferro alloys, aluminium, limestone and dolomite use. Of the total CO_2-eq GHGs emitted from the industrial processes, 42 per cent was from iron and steel production, 30 per cent from cement production, 14 per cent from ammonia production, 6 per cent from limestone and dolomite use and the rest of the processes contributed the remaining 8 per cent.

In 1994, the agriculture sector contributed 29 per cent of the total CO_2-eq GHG emissions, amounting to 3,44,485 Gg CO_2-eq. The agriculture sector primarily emitted CH_4 and N_2O. The CO_2 emissions due to the energy use in the agriculture sector are accounted for as a part of all energy emissions. The emissions sources accounted for in the agriculture sector are enteric fermentation in livestock, manure management, rice cultivation, agricultural soils and burning of agricultural crop residue. The bulk of the GHG emissions from the agriculture sector were from enteric fermentation (59 per cent), followed by rice paddy cultivation (23 per cent), and the rest were contributed by manure management, burning of agriculture crop residue and application of fertilizers to soils.

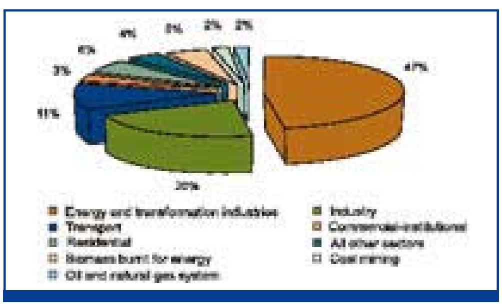


Figure 2.3: Relative GHG emissions from energy sector activities in 1994.

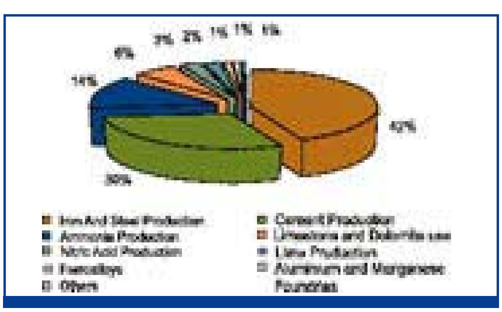


Figure 2.4: Relative GHG emissions from industrial processes in 1994.

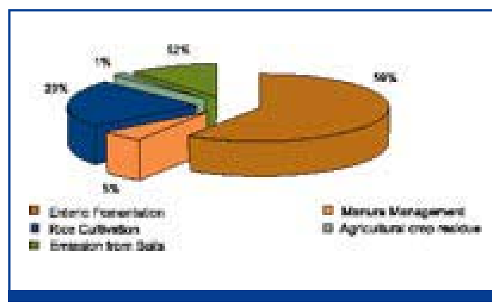


Figure 2.5: Relative GHG emissions from agriculture sector activities in 1994.

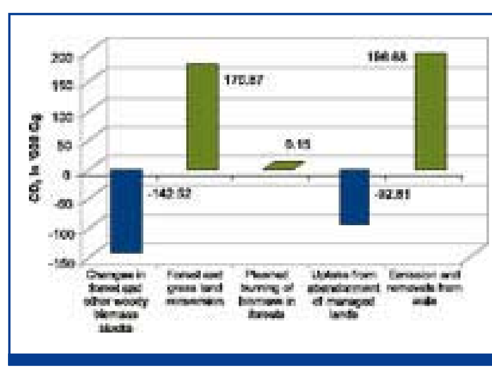


Figure 2.6: Relative GHG emissions from land use, land-use change and forestry sector activities in 1994.

GHG emissions from land use, land-use change and forestry (LULUCF) sector are an aggregation of emissions from changes in forests and other woody biomass stock, forest and grassland conversion, abandonment of managed lands and forest soils. The net CO_2-eq. emission from this sector was 14,292 Gg, which includes CO_2 emission and sequestration, as well as the emission of CH_4 and N_2O. The LULUCF sector emitted 14,142 Gg net CO_2 in 1994. Methane and N_2O emissions from this sector in terms of CO_2 equivalent, were 136.5 Gg CO_2-eq and 12.4 Gg CO_2-eq respectively.

The disposal of waste and the processes employed to treat these wastes give rise to GHG emissions. The two main sources of GHGs from the waste sector in India are municipal solid waste disposal and waste-water handling for commercial and domestic sectors. The collection of waste primarily takes place in large cities. In smaller cities and towns, waste decomposes under aerobic conditions and thus, methane is not emitted. Industrial waste-water in India is treated as per the mandate of the MoEF by large industrial units. The total GHGs emitted from the waste sector in 1994 was 23,233 Gg CO_2-eq, which is 2 per cent of the total national CO_2 equivalent emissions. Out of this, the major contribution was from municipal solid waste disposal activities (53 per cent), followed by domestic waste water, which contributed 32 per cent of the total GHG emissions from the sector (see Figure. 2.7).

GAS BY GAS EMISSION INVENTORY

The following section details a gas-by-gas inventory of CO_2, CH_4 and N_2O emitted from the all energy, industrial processes, agriculture, LULUCF and waste sectors.

CO_2 emissions

CO_2 emissions from all energy, industrial processes and LULUCF activities constituted 65 per cent of the total GHG emissions in 1994. The relative contribution of the three activities to the net CO_2 released from India were 85 per cent, 13 per cent and 2 per cent respectively (Figure 2.8). CO_2 emissions from the energy sector include those from fossil fuel combustion. CO_2 emissions from biomass are treated as carbon-neutral at the combustion point. Change in

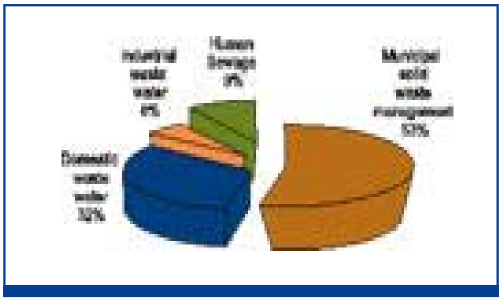


Figure 2.7: Relative GHG emission (in terms of CO_2 eq.) from waste disposal activities.
Note: MSW: Municipal Solid Waste, DMW: Domestic Waste-water, IWW: Industrial Waste Water and HS: Human Sewage.

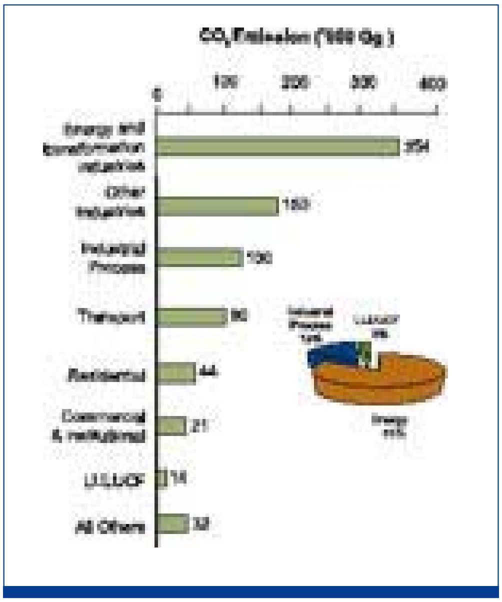


Figure 2.8: Relative CO_2 emissions from different sectors in 1994.

biomass is accounted separately in the LULUCF sector. The industrial processes, which includes processes like iron and steel manufacturing and cement production are also major sources of CO_2 emission. The total CO_2 emissions from India in 1994 were 8,17,023 Gg and removals by sinks were around 23,533 Gg (Table 2.2).

Energy

Fossil fuels contributed 95 per cent of the total commercial energy consumed in India in 1994, with the remaining 5 per cent derived from sources like

Table 2.2: CO_2 emissions from India in 1994

GHG source and sink categories (Gg)	CO_2 (Emissions)	CO_2 (Removals)
Total CO_2	**817023**	**23533**
1. All Energy	**679470**	
Energy and transformation industries	353518	
Industry	149806	
Transport	79880	
Commercial/institutional	20509	
Residential	43794	
All other sectors	31963	
2. Industrial Processes	**99878**	
Cement production	30767	
Lime production	1901	
Lime stone and dolomite use	5751	
Soda ash use	273	
Ammonia production	14395	
Carbide production	302	
Iron and steel production	44445	
Ferro alloys production	1295	
Aluminium production	749	
3. Land use, Land-use change and Forestry	**37675**	**23533**
Changes in forest and other woody biomass stock		14252
Forest and grassland conversion	17987	
Uptake from abandonment of managed lands		9281
Emissions and removals from soils	19688	
4. Emissions from Bunker fuels #	**3373**	
Aviation	2880	
Navigation	493	

not included in national totals.

hydropower, nuclear and renewable energy (Planning Commission, 2002). Fossil fuels combustion contributed 91 per cent to total CO_2 emissions, with coal accounting for nearly 62 per cent.

Fossil fuel Combustion

During fossil fuel combustion, the carbon stored is emitted almost entirely as CO_2. The amount of carbon in fuels per unit of energy content varies significantly by fuel type for example coal contains the highest amount of carbon per unit of energy, while petroleum products in comparison have about 25 per cent less carbon than coal and natural gas about 45 per cent less.

In India, domestic coal is the main energy source. Coal contributed 62 per cent to the total CO_2 emissions in 1994. In comparison, petroleum products contributed 31 per cent and natural gas seven per cent.

The power sector is the highest contributor to Indian GHG emissions.

Keeping in view the importance of coal in the Indian energy system, and the fact that there is a wide variation in the ash content, moisture content and petrographic makeup of Indian coal, it is vital to estimate the Net Calorific Values (NCVs) and Carbon Emission Factors (CEF) used for estimating the CO_2 emission due to coal combustion under indigenous conditions. In India the coal is classified in three main categories — coking, non-coking and lignite. The NCV for each has been estimated separately, rather than assuming the identical average values for each category. The NCV values of the coals were derived from the Gross Calorific Value (GCV) of the fuel and its available hydrogen content. Both these parameters vary with the type, grade and maturity (rank) of coal.

Data on proximate, ultimate and heat value of different types of coal were collected from primary sources and secondary sources such as technical reports of Central Fuel Research Institute, a premier institute in India researching on coal for many decades. The analysis used the data collected over the past one and a half decades. Carbon content of the different coals – were measured on – a dry mineral matter free basis (dmmf) by taking into consideration the moisture contents and Gross Calorific Value (GCV). For non-coking coal, data were segregated on the basis of major coalfields, like Eastern coalfields, Western coalfields, South Eastern Coalfields, Central Coalfields. The NCV was calculated using the formula, NCV= GCV- 53 x H, where H is the available hydrogen. GCV and hence NCV vary with type and grade of coal and depend on the maturity (rank).

Ash and moisture contents of coal have significant influence on the NCV estimates. The internationally accepted norm of estimating NCV at 96 per cent moisture level of coal, called capacity moisture, was used in the present estimates. The ratio of Carbon to heat content (NCV) was computed to arrive at the CEF. The NCVs used in the Indian estimates is given in Table 2.3.

Table 2.3: India-specific CO_2 emission coefficients.

	India-specific	
	NCV	CEF
	TJ/Kt	t CO_2/TJ
Coking coal	24.18±0.3	25.53
Non-coking coal	19.63±0.4	26.13
Lignite	9.69±0.4	28.95

In order to estimate CO_2 emissions from the burning of petroleum and natural gas, the IPCC default emission coefficients were used. Time and resource limitations did not permit the measurements to be carried out for refineries that convert crude to refined products. In the case of petroleum products and natural gas, the use of default emissions would be fairly accurate due to relatively low variation in quality of these fuels across the globe, as compared to coal. The future refinements of inventory estimations would consider specific measurements to assess the CO_2 emission factors from petroleum as well as refined products, such as liquefied petroleum gas, gasoline, naphtha, jet kerosene, other kerosene, diesel oil, residual fuel oil, lubricants and other oils.

CO_2 emissions from fossil fuel combustion in various sectors are presented next.

Energy and Transformation Industries

CO_2 emissions from the energy and transformation industries mainly include the power generation and petroleum refining industries. These sectors together emitted 3,53,518 Gg of CO_2 in 1994.

Industry

CO_2 emissions from the industry sector are estimated by taking into account emissions from paper, sugar, cement, iron and steel, textile, bricks, fertilizer, chemical, aluminium, ferroalloys, non-ferrous, food and beverages, leather and tannery, jute, plastic, mining and quarrying, rubber, and all other industries. Coal and petroleum oil products are used in these industries as energy sources in substantial quantities. The total CO_2 emitted from this sector in 1994 was 1,49,806 Gg.

Commercial

End-use activities like cooking, lighting, space heating, space cooling, refrigeration and pumping characterize the commercial sector. The fuels consumed by the commercial sector are electricity (for lighting, heating, cooling, and pumping), LPG (for cooking), kerosene (for lighting and cooking), diesel (for generating power for pumping and lighting), coal,

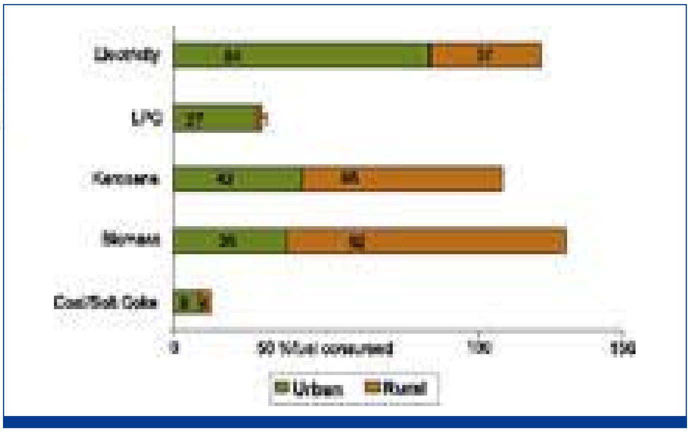


Figure 2.9: Share of fuels for cooking and lighting in rural and urban households.
Source: *Fifty-fourth National Sample Survey conducted by National Sample Survey Organization, 1998-1999.*

charcoal and fuel wood (for cooking). The total CO_2 emission from this sector in 1994 was 2,05,09 Gg.

Residential

Energy consumed in the domestic or the residential sector is primarily for cooking, lighting, heating and household appliances. The energy ladder for residential cooking in India follows the classic pattern vis-à-vis income, moving from the bottom-rung biomass (dung cakes, crop residues and fuel wood) to coal, kerosene, LPG and electricity. There are significant urban-rural differences in the energy profile of households, in terms of supply as well as consumption. Figure 2.9 gives the share of various fuels for cooking and lighting needs in Indian urban and rural households. The total CO_2 emission from this sector in 1994 was 4,37,94 Gg. This excludes CO_2 emission from biomass burning, since biomass is considered to be carbon neutral.

Transport

Another major sector contributing to GHG emissions is transportation, which includes road, rail, aviation and navigation. The total CO_2 emissions from this sector in 1994 were 79,880 Gg. Among transport sub-sectors, road transport is the main source of CO_2 emissions and accounted for nearly 90 per cent of the total transport sector emissions in 1994. Road transport is characterized by heterogeneous gasoline-fuelled light vehicles and diesel-fuelled heavier vehicles. According to the survey by the Indian Market Research Bureau on behalf of the Ministry of Petroleum and Natural Gas (MoPNG, 1998), the transport sector consumed nearly all (98.3 per cent) of gasoline in the country (see Figure 2.10 and Table 2.4). The share of vehicle

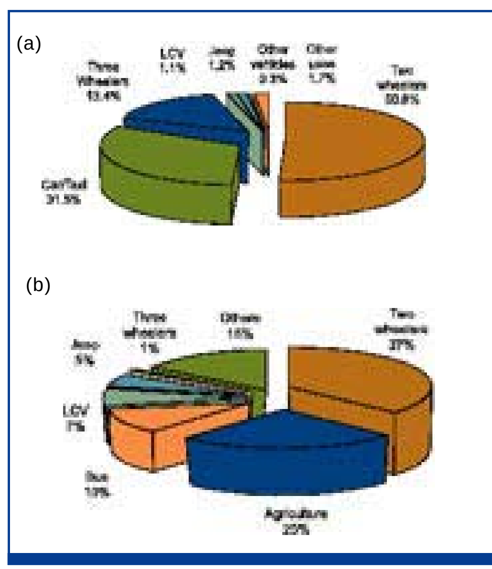


Figure 2.10: All-India end-use consumption of (a) gasoline and (b) diesel use in the transport sector.
Source: Ministry of Petroleum and Natural Gas, Government of India, 2002.

Improved *chullah.*

Table 2.4: Share of diesel and gasoline demand from retail outlets in various sectors.

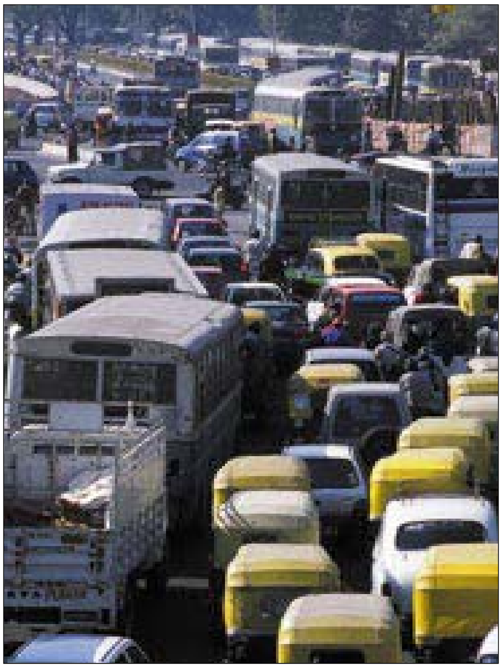
End-use Segment	(%)
DIESEL	
1. Road Transport	
Car / Taxi	4.8
Jeep	5.2
Three-wheeler	1.2
Truck	34.7
LCV	6.7
Bus	9.2
Sub-Total	**61.8**
2. Agriculture	
Tractor	14.3
Pump set	5.2
Tiller/Thresher/Harvester	4.0
Sub - Total	**23.5**
3. Others	
Power generation	7.8
Industrial applications	3.0
Others / Miscellaneous	3.9
Sub-Total	**14.7**
Total	**100.0**
GASOLINE	
1. Road Transport Sector	
Two-wheelers	50.8
Three-wheelers	13.4
Car / Taxi	31.5
LCV	1.1
Jeep	1.2
Other Vehicles	0.3
Sub-total	98.3
2. Other uses	
Truck	0.1
Tractor	0.4
Pump set	0.2
Power	0.3
Others	0.7
Sub-total	1.7
Total	**100.0**

Source: MoPNG (1998), All India Survey of Gasoline and Diesel Consumption. A survey conducted by the Indian Market Research Bureau for the Ministry of Petroleum and Natural Gas, Government of India, New Delhi.

categories in gasoline consumption was two-wheelers (50.8 per cent), car/taxi (31.5 per cent) and three-wheelers (13.4 per cent).

Diesel is consumed in both private and public modes of transport (trucks, buses, jeeps, cars/taxis, etc.), as well as in agriculture (tractors, irrigation pumps, etc.). The all-India survey (MoPNG, 1998) indicated that 61.8 per cent of the diesel sold through the network of retail outlets was consumed by road transport. Shares of different end-uses in diesel and gasoline consumption are detailed in Table 2.4 and the consumption in Figure 2.11.

Automotive exhaust emissions are amongst the major sources of toxic pollutants, besides producing GHG emissions like CO_2, CH_4 and N_2O. The vehicular emissions norms, first introduced in India in 1991-1992, were focused on reducing the toxic pollutants. The norms were subsequently upgraded in 1996 and 2000. Presently, the emission norms equivalent to Euro — I prevail in the entire country, and Euro — II in the metropolitan cities. The Government of India has made significant policy interventions, including



The technology-level activity data for the road transport sector requires refinement.

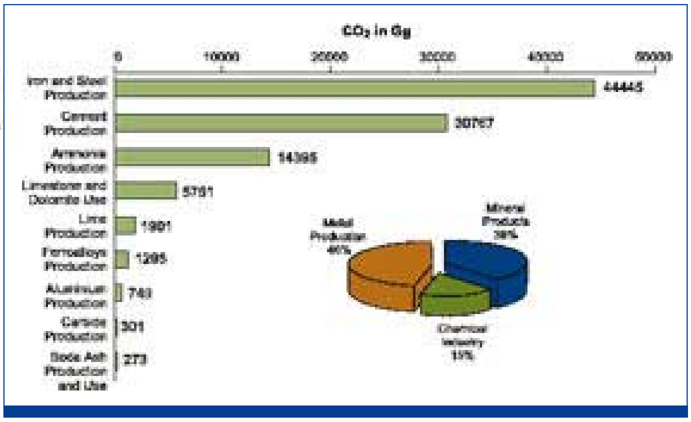


Fig. 2.11: Relative emission of CO_2 from various industrial processes in India in 1994. Others include CO_2 emissions from soda ash and carbide productions.

Table 2.5: Road Map for New Vehicles.

Coverage	Passenger Cars, light commercial vehicles & heavy duty diesel vehicles[!]	2 and 3 wheelers
All-India	Bharat Stage II[*] - 1.4.2005 EURO III Equivalent - 1.4.2010	Bharat Stage II - 1.4.2005
11 major cities (Delhi / NCR, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur & Agra)	Bharat Stage II - 1.4.2003 EURO III Equivalent - 1.4.2005 EURO IV Equivalent - 1.4.2010	Bharat Stage III[+] - Preferably from 1.4.2008 But not later than 1.4.2010

* EURO II equivalent Indian vehicular emissions norms
+ To be reviewed in 2006 for enhanced implementation
! Bharat Stage II norms to come into force for two wheelers and 3 wheelers manufactured on or after 1.4.2005

Source: Auto Fuel Policy, Ministry of Petroleum & Natural Gas, Government of India, New Delhi, October 2003.

continuous improvements in the emissions norms to alleviate the air quality in the urban centres in the wake of rapidly growing vehicular population. The recent years have witnessed a phenomenal growth in road transport vehicles (see Table 2.5). This increasing trend in vehicle population is expected to continue, with rising incomes and enhanced vehicular choices before the consumers. The emissions of local pollutants in urban centres have therefore, continued to grow along with the rising GHG emissions.

The deterioration in urban air quality led to several response measures, like the introduction of CNG vehicles, improvement in auto fuel quality and enhancement of road infrastructure. The Government of India announced the Auto Fuel Policy in 2003, which comprehensively addresses the issues of vehicular emissions, vehicular technologies and the provision of cleaner auto fuels in a cost-efficient manner while ensuring the security of fuel supply. The policy includes the road map for reduction in emission norms for new vehicles (Table 2.5). Besides proposing the enhanced quality of liquid fuels, the policy encourages the use of CNG/LNG in the cities affected by high vehicular pollution to enable the vehicle owners a wider choice of fuel and technology. The policy envisages the accelerated development of alternate technologies, like battery and fuel cell-powered vehicles and a comprehensive programme for research and development support and other measures for zero emissions vehicles. The implementation of the Auto Fuel Policy would accrue significant improvement in local air quality and also contribute to the reduction in emissions of GHG.

The 1994 emissions inventory assessment, had to take into account a mix of vehicle technologies that was distinctly different from the present vehicular stock. The emission coefficients for different types of vehicle using gasoline and diesel were estimated by assessing emissions from the vehicles of 1994 vintage, a mix of vehicles and road conditions similar to those in 1994 (Table 2.6).

Table 2.6: India-specific CO_2 emission coefficients developed for the road transport sector.

Categories	t CO_2/TJ
Gasoline	
2W/3W	43.9 ± 7.3
Car/Taxi	61.5 ± 4.0
Diesel Oil	
MCV/HCV	71.4 ± 0.55
LCV	71.4 ± 0.5

All other sectors

All other sectors cover those areas of the economy that are not included elsewhere for the purpose of accounting energy consumption. The total emission of CO_2 from this sector in 1994 is estimated to be 31,963 Gg.

Industrial Processes

Emissions are produced as a by-product of many non-energy related activities, such as industrial processes that chemically transform raw materials. The major industrial processes that emit CO_2, include cement production, iron and steel production, lime production, lime stone and dolomite use, soda ash manufacture and consumption, ammonia production, ferroalloys production, aluminium and manganese foundries, and calcium carbide production.

The total CO_2 emissions from the industrial processes in India were estimated at 99,878 Gg in 1994. Cement and iron and steel manufacturing processes were the key source categories for CO_2 emissions in the industrial processes sector. These two contributed nearly three-quarters, i.e., about 75,212 Gg CO_2. Emissions from these sectors were estimated following the IPCC Tier-II methodology. The rest of the emissions from ammonia production, limestone and dolomite use, production of lime, ferroalloys, manufacturing, aluminium and manganese foundries and others were estimated using the IPCC Tier-I methodology. The relative emission of CO_2 from the industrial process sector is shown in Figure 2.11. CO_2 emissions from metal production had a dominant share at 46 per cent, the production of mineral products contributed 39 per cent and the remaining were contributed by the chemical industry.

Cement Manufacture

Cement production in India has risen from about 45 Mt in 1990 to about 106 Mt in 2001 (CMA, 2002), however the per capita cement consumption in India remains among the lowest in the world (100 kg per capita as compared to a world average of 267 kg per capita).

In view of the significant contribution of CO_2 emission from cement manufacturing process, an indigenous CO_2 emission coefficient was developed (Box 2.1). Clinker samples were collected from various plants of different technologies and sizes. Based on the analysis of this data, the average CO_2 emission coefficient for cement production process in 1994 was estimated to be 0.537 tonne CO_2 per tonne of clinker for India. Using this, the total CO_2 emitted in the country in the year 1994, was estimated to be 30,767 Gg.

Lime production

Lime is used in the steel and construction industry, pulp and paper manufacturing, sugar production, the fertilizer industry, and for water and sewage treatment plants. It is manufactured by heating limestone, mostly $CaCO_3$, in kilns, producing calcium oxide (CaO) and CO_2, which is normally emitted into the atmosphere. The lime-producing sector in India consists of unconsolidated, small-scale enterprises. The main constraint for GHG inventory estimation for this sector is the paucity of data. The industries considered as 'high lime industries', not using limestone as flux, are sugar and paper, and emissions from lime production in these industries have been accounted for under this sector (Indian Mineral Year Book, 1995). The lime content (or CaO) in limestone generally varies between 40 per cent and 50 per cent. As all varieties of limestone are used in lime kilns, the average lime content in limestone, for the purpose of assessing the quantity of lime produced, has been estimated at 45 per cent. Under these assumptions, the amount of CO_2 emitted in 1994 from limestone production is estimated to be 1901 Gg.

Limestone and dolomite use

Limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are basic raw materials used by a wide variety of industries, including construction, agriculture, chemicals and metallurgical industries. For example,

Box 2.1: Determination of CO_2 emission coefficient from cement manufacturing process

Carbon dioxide emissions in the cement manufacturing process originate from the calcination of limestone at very high temperatures. The CO_2 emission factor is estimated from this process by using CaO content and CKD (Clinker-to-Dust) loss. Magnesium carbonate ($MgCO_3$) present in limestone also liberates CO_2 during calcination. Therefore the MgO content of the limestone used also needs to be estimated. The CaO content in Indian clinkers normally varies from 62 to 66 per cent. The CaO content from each plant varies because the source materials are different. The MgO content, in Indian clinkers, varies from 0.5 to 6.0 per cent. This value is dependent on the raw material source. Though IPCC considers a default cement kiln dust (CKD) loss at 2.0 per cent of clinker produced, however, due to the stringent control on particle emission by Indian pollution control boards (PCBs), most of the cement kilns are provided with appropriate pollution control measures to keep the CKD within the prescribed limits of as low as 0.03 per cent.

For estimating the CO_2 emission coefficient due to the manufacturing of cement, clinker samples were collected from various plants of different technologies and analyzed using the X-Ray Fluorescence method (XRF) for CaO and MgO for on-line process control. Hourly cement samples were pooled in each shift, and analyzed using the wet method for CaO and MgO contents. The yearly average values of CaO and MgO contents were then used to estimate the emission factor. Using these methods the emission factor, which is a product of CO_2, generated from CaO and MgO, the content of the clinker and the correction factor for CKD losses from the plant was estimated by using the equation:

Emission factor = (Fraction of CaO content in clinker * 0.7848 + Fraction of MgO content in clinker * 1.0915) *(1+ CKD losses from the plant)

The average CaO and MgO content of the raw material was found to be 64.7 per cent and 2.01 per cent respectively in 2001-2002 which have been actually maintained more or less at the same level, right from inception. However, as the technology of production has changed from the wet to semi-wet, to the dry process, the CKD losses have reduced from a level of 2 per cent in 1980, to an average of 0.025 in 2001-2002. By interpolation between these periods with an average of 1.0 per cent of the capacities created from 1980 up to 1985; 0.5 per cent of the capacities created from 1985 to 1990; 0.05 per cent of the capacities created from 1990 to 1995; and 0.05 per cent of the capacities created from 1995 to 2000; and 0.025 per cent till now, the weighted average CKD loss can be calculated. Based on this assumption, the CKD loss for 1994 will be 1.38 per cent. Using this data, it was estimated that the weighted average emission factor for the cement industry in India is in the range of 0.534 to 0.539 tonnes per tonne of clinker for large cement manufacturers, for the year 1994.

limestone is used in the case of iron ore, where limestone heated in a blast furnace reacts with the impurities in the iron ore and fuels, generating CO_2 as a by-product. Limestone is also used in refractories.

CO_2 emissions were estimated for major manufacturers, which account for 75 per cent of the total dolomite consumption. The activity data (Indian Mineral Year Books, 1982-2001) used for the estimation of emissions is the quantity of limestone and dolomite used annually. The estimates exclude the use of limestone by cement and high lime industries such as sugar, paper and lime kilns, as emissions from these sectors have been reported under 'lime production'. The total CO_2 emitted due to limestone and dolomite use in 1994 is estimated at 5,751 Gg.

Soda ash use

Soda ash has diverse applications in industries like glass, soap and detergents, textiles and food. Since the data for specific application areas is not reliable, the uncertainty associated with the emissions estimates for this sector is likely to be very high. The total CO_2 emitted in 1994 from soda ash use is estimated at 273 Gg.

Ammonia production

The majority of ammonia production takes place in fertilizer manufacturing units in India. The Tier-I approach was adopted to estimate emissions from this sub category, using an average of IPCC default emission factors. The total CO_2 released due to ammonia production is 14,395 Gg.

Carbide production

CO_2 is produced during the manufacturing process of calcium carbide and silicon carbide. Calcium carbide is made by heating calcium carbonate and subsequently reducing CaO with carbon derived from petrol coke. Both these steps lead to the emission of CO_2. The most important application of calcium carbide is the production of acetylene. CO_2 is released in the production of silicon carbide as a by-product of a reaction between quartz and carbon.

Emissions from the three stages of calcium carbide and use, namely, the use of coal as a reducing agent, the use of limestone and use of calcium carbide for different applications were estimated. IPCC Tier-I methodology and IPCC default emission factors have been applied for all three stages. The total CO_2 emitted from this sector in 1994 was 302 Gg.

Iron and steel production

The iron and steel production process contributed a little more than half the CO_2 emissions from the industrial processes sector in 1994. Process emission of CO_2 in an iron and steel plant takes place during coke oxidation. Additional emissions occur as the limestone flux gives off CO_2 during reduction of pig iron in the blast furnace, but this source is covered as emissions from the limestone use. There are two processes of production that are common in India, namely integrated steel plants (technically defined as blast furnace open hearth and basic oxygen furnace), and mini steel plants scrap or sponge iron based Electric Arc Furnaces (EAF).

The coal consumption data in this sector is accessed directly from the consumption end (SAIL, 1984, 1986, 1988, 1990, 1992, 1994, 1996, 1998, 2000). Emissions from this sub-sector can be ascribed to three distinct sources from the use of coal as reducing agents in the blast furnace, from the production of steel from pig iron and from graphite electrodes in EAF.

Tier-II methodology was used to estimate emissions from the production of steel from pig iron. Emissions factors for reducing agents based on NCV of coal (of 2.26 t-C/t coal) and communication with different EAF units in the country (14 kg C/t) was used. Thus, the total CO_2 released due to manufacturing of iron and steel in India in 1994 was estimated to be 44,445 Gg.

Ferroalloys production

In ferroalloys production, raw ore, coke and slagging materials are smelted together under high temperature. During the smelting process, a reduction reaction takes place. Carbon captures the oxygen from metal oxides to form CO while the ores are reduced to molten base metals. The component metals are then combined in the solution. In covered arc furnaces, the primary emissions are entirely CO, however, it is assumed that all CO is converted into CO_2 within days afterwards.

The activity data is ideally, the quantity of the reducing agent consumed or alternatively, it is the quantity of ferroalloys produced (SAIL, 2000; IFAPA, 2000). In the present calculations, the annual production volumes of the different types of ferroalloys were used as activity data. Using IPCC default emissions factors for the various types of ferroalloys produced in the country, the total CO_2 emission estimated due to smelting of ores was 1,295 Gg.

Aluminium production

Aluminium is produced in two steps. First, the bauxite is ground, purified and calcinated to produce alumina. It is then electrically reduced to aluminium by smelting. CO_2 is emitted during the electrolysis of alumina to aluminium using a graphite electrode as the source of carbon for reduction.

To estimate CO_2 emissions from the production of aluminium, the activity data used is the quantity of aluminium produced annually. Data on aluminium production (MoSM, 1988-1999) has been obtained according to the technology used in each manufacturing unit. IPCC default emission factors for the Soderberg and pre-backed anode processes have been applied to estimate emissions from this industry. Aggregate production from all manufacturing units has been used to estimate emissions at the national level. The total CO_2 emitted from aluminium production in 1994 was 749 Gg.

Land use, land-use change and forestry

In this sector, the fundamental basis for GHG inventory estimates rests upon the fact that the flux of CO_2 to or from the atmosphere is assumed to be equal to the changes in carbon stocks in existing biomass and soils, and that changes in carbon stocks can be estimated by first establishing rates of change in land use and the practices used, to bring about the change (e.g., burning, clear cutting and selective felling etc.). The IPCC approach involves four estimates of carbon stock changes due to; (a) changes in forest and other woody biomass stocks; (b) forest and grassland conversion; (c) uptake from abandonment of managed lands; and (d) emissions and removals from soils.

The methods adopted and quality of data used for the present Indian inventory falls into the Tier-II category. All activity data and most emission/sequestration factors used are from national sources. Some of the data used is from field measurements and forest inventory sources, normally associated with Tier-III. India presently does not have a National Forestry Inventory (NFI) Programme which undertakes repeated measurements from the same plots for estimating rates of changes for several parameters, such as average annual biomass growth rate, changes in soil carbon density and growing stock of biomass.

The area under forests (including tree plantations) in India was estimated to be 63.33 Mha in 1994. The forest area in India is categorized into 22 strata according to the Forest Survey of India (FSI), based on the dominant tree species. The forests which could not be categorized as any other forest strata, are included under 'Miscellaneous Forest', which accounts for 64

Land use, land-use change.

per cent of the forest area. The distribution of forests, excluding miscellaneous forests, is dominated by *Shorea robusta (*Sal*)* and *Tectona grandis* (Teak) species occupying 12 per cent and 10 per cent of the total forest area, respectively. The area under different forest type is shown in Figure 2.12.

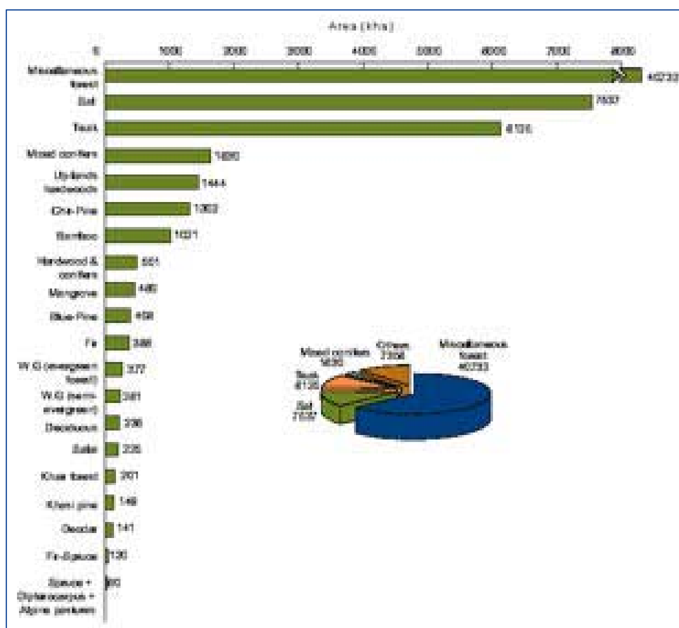


Fig. 2.12: Area under different forest types in India (miscellaneous forests are not included).
Source: *FSI, 1993, 1994 and 1995. Status of Forest Report, Forest Survey of India, Dehradun.*

Changes in forest and other woody biomass stock

The CO_2 emission from changes in forest and other woody biomass stocks is the result of net changes in carbon stock from the growth in biomass and losses from extraction of biomass. The total carbon uptake in forests is estimated first by categorizing forest area into different strata, then by estimating the area under each of the forest stratum and by obtaining an average annual growth rate from the literature and field measurements. Thus, the total carbon uptake is estimated by multiplying the area under each forest stratum and average annual biomass increment and aggregating the overall 22 forest strata. The annual biomass increment was estimated to be 77.0 Tg-C and the total carbon release due to commercial extraction of timber and traditional wood use is 73.2 Tg-C. The net CO_2 uptake in 1994 from changes in forest and other woody biomass stock was 14.2 Tg-CO_2, or 14,252 Gg.

Forest and grassland conversion

The annual loss of biomass due to forest conversion was estimated to be 12.09 Tg, in 1994. In India, the quantity of biomass lost due to on-site burning is due to the conversion of forests to agriculture on account of shifting cultivation mainly in the north-eastern region. The woody biomass left for decay after conversion is assumed to be insignificant or nil, as all woody biomass is likely to be collected and used as fuelwood by the local communities. The total quantity of carbon dioxide released from on-site and off-site burning and biomass left for decay is estimated to be 17,987 Gg.

Uptake from abandonment of managed lands

The total CO_2 uptake is estimated by multiplying the area of abandoned land and the mean annual biomass growth rate. Thus, the total CO_2 uptake in managed land that is abandoned and subjected to regeneration is estimated to be 9281 Gg. Area left abandoned for over 20 years is assumed to be nil, as no such lands may exist due to the following reasons: (a) if the land has acquired a tree crown of over 10 per cent, it would have been classified as forest and included under forests; (b) land may have been converted to cropland or non-agricultural lands; and (c) in a 20-year period, the land may have completely degraded and turned into barren land with no above ground biomass growth.

Emission and removals from soils

The sources and sinks of CO_2 in soils are associated with changes in the amount of organic carbon stored in soils. The release of CO_2 also occurs from inorganic sources, either from naturally occurring carbonate minerals, or from applied lime. Therefore, estimations under this category take into account: (a) estimates of change in soil carbon from mineral soils; (b) CO_2 emissions from intensively managed organic soils; and (c) CO_2 emission due to liming of agricultural soils. Change in soil carbon from mineral soils due to change in land management or use is estimated by taking into account the total land area categorized into 22 forest strata and seven other land use systems[3] covering cropland, fallow land, non-agricultural land, etc. The area under these forest and non-forest land-use systems is estimated for 1984 and 1994 (http://planningcomission.nic.in/data/dataf.htm). Soil carbon density (tC/ha) in the top 30 cm for each land-use system is obtained from literature as well as field measurements. The total soil carbon stock is estimated for all land-use systems for 1984 and 1994. The difference in carbon stock averaged over 10-year period is estimated as net emission of CO_2 for 1994. Following this methodology, the net change in soil carbon stock in mineral soils averaged over a 10-year period (1984 to 1994) for 1994 is estimated to be 19.68 Tg CO_2. CO_2 emissions from intensively managed organic soils could not be estimated as the area under organic soils, subjected to change is marginal or zero due to the fact that area under organic soil is very limited. Further, such lands may have been converted long before 1994, or are likely to be under protection, and data available on changes, if any is limited. For example, there is no data available on lime application to soil at the national level. Lime application is not prevalent on any significant scale in India and is thus not considered. Therefore, CO_2 emissions from liming ($CaCO_3$) of

[3] The soil carbon for forest types is based on literature for the 22 forest strata compiled by Forest Research Institute of India and carbon density (t C/ha) for the seven non-forest land use categories was deduced from field soil sampling and laboratory measurements up to a depth of 30 cm.

agricultural soils is not estimated. Considering all these aspects, the net CO_2 emission from agriculturally impacted soils (land-use management) is estimated to be 19,788 Gg.

Considering gross CO_2 emissions and removals for the land use, land-use change and forestry sector, the net CO_2 emissions, for the inventory year 1994 is estimated to be 14,142 Gg of CO_2, which is less than 2 per cent of national CO_2 emissions.

Methane (CH_4) emissions

Atmospheric methane is an integral component of the greenhouse effect, second only to CO_2 as a contributor to the total anthropogenic GHG warming in the atmosphere. The overall contribution of CH_4 to global warming is 21 times more effective at trapping heat in the atmosphere with respect to CO_2 (IPCC, 1996). From the pre-industrial times to the present, the concentration of CH_4 in the atmosphere has increased 151 times (IPCC, 2001a). The main factors contributing to this increase are: proliferation in activities related to exhaustive mining of coal for energy use; emissions due to handling of oil and natural gas systems; dependence on products derived from livestock; waste management; increased production of rice to meet the demand of the growing population; on-site burning of crop residue for preparing the fields for the next cropping; cycle management of solid waste; and waste water from the domestic and the industrial sectors. In the following section, the CH_4 emissions in India from these sources are presented in Table 2.7.

Table 2.7: National Methane emissions in 1994.

Total national CH_4 Emission in Gg	**18083**
1. All Energy	**2896**
Transport	9
Fuel combustion	
Biomass burnt for energy	1636
Fugitive Fuel Emission	
Oil and natural gas system	601
Coal mining	650
2. Industrial Processes	**2**
Production of carbon black and styrene	2
3. Agriculture	**14175**
Enteric fermentation	8972
Manure management	946
Rice cultivation	4090
Agricultural crop residue	167
4. Land use, Land-use change and Forestry	**6.5**
Trace gases from biomass burning	6.5
5. Waste	**1003**
Municipal solid waste disposal	582
Domestic waste water	359
Industrial waste water	62

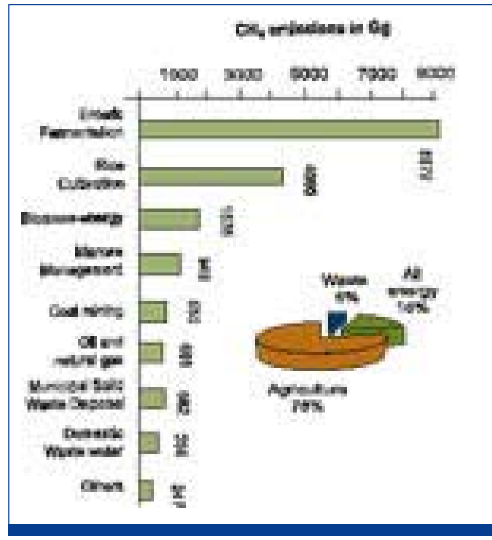


Figure 2.13: Relative methane emission from different anthropogenic activities in 1994.

The total national CH_4 emission in 1994 from the above-mentioned sources was 18,083 Gg. The agriculture sector dominated with 78 per cent of the total national CH_4 emissions, within which emissions due to enteric fermentation (8,972 Gg) and rice cultivation (4,090 Gg) were the highest. Of such emissions 16 per cent came from the energy systems comprising emissions due to biomass burning, coal mining and handling and flaring of natural gas systems. Waste disposal activities contributed about 6 per cent of the total CH_4. Methane emissions from the LULUCF sector were minor in nature, mainly due to the burning of biomass in forests. Similarly, the contribution of the industrial process sector to the total national CH_4 emissions is miniscule in comparison with other sources and is only around 2 Gg. The sectoral distributions of CH_4 emissions from India in 1994 are shown in Figure 2.13.

Energy

Biomass burning

The combustion of biomass leads to emission of methane and other trace gases. In India, about 60 per cent of households depend on traditional sources of energy, like fuelwood, dung cake and crop residue for meeting their cooking and heating needs (Planning Commission, 2002). Using IPCC default emission coefficients, the amount of CH_4 released in 1994 was 1,636 Gg. High uncertainties are associated with this estimate as biomass activity data are based only on small surveys carried out at different points of time. More exhaustive surveys are required to establish the quantity of various types of biomass used in the country.

Coal mining

Methane trapped in the coal seams during its formation million of years ago, is released when it is mined. The quantity of methane released depends primarily on the depth of and type of coal that is being mined. India's total coal resources are estimated at 206 Bt up to a depth of 1200 metres. The recoverable coal reserves, estimated at 75 Bt are capable of supplying coal for over 250 years at current levels of production, or more than 125 years at double the existing rate of production, which may very likely be the demand of coal a decade later. Lignite reserves in the country have been estimated at around 34,763 Mt out of which 30,275 Mt are recoverable. About 425 mines are the major producers of coal in India, contributing approximately 90 percent of national coal production. The production programme from the existing coal producers includes both opencast and underground methods of mining.

Box –2.2: Gassiness of Indian mines

Degree I: means a coal seam or part thereof within the precincts of a mine not being an opencast working, whether or not inflammable gas is actually detected in the general body of the air at any place in its workings below ground, or when the percentage of the inflammable gas, if and when detected, in such general body of air does not exceed 0.1 and the rate of emission of such gas does not exceed one cubic meter per tonne of coal produced.

Degree II: means a coal seam or part thereof within the precincts of a mine not being an opencast working in which the percentage of inflammable gas in the general body of air at any place in the workings of the seam is more than 0.1 or rate of emission of inflammable gas per tonne of coal produced exceeds one cubic meter but does not exceed ten cubic meters.

Degree III: means a coal seam or part thereof within the precincts of a mine not being an opencast working in which the rate of emission of inflammable gas per tonne of coal produced exceeds ten cubic meters.

Based on mine-specific rate of emission of methane, all the underground coal mines in India have been categorized into Degree I, Degree II and Degree III (see Box 2.2 and Figure 2.14) by the Directorate General of Mines Safety (DGMS, 1967). There is no such classification for opencast coal mines, as the associated methane emission is not very high and emitted gas immediately diffuses into the atmosphere.

Considering the vast deposits of coal with varying degrees of gas content, it was deemed necessary to estimate the CH_4 emission coefficients representing the indigenous conditions. Extensive field investigations were carried out, involving the measurement of velocity of air passing through the return airways separately in each ventilating district and in the main body, with the help of the

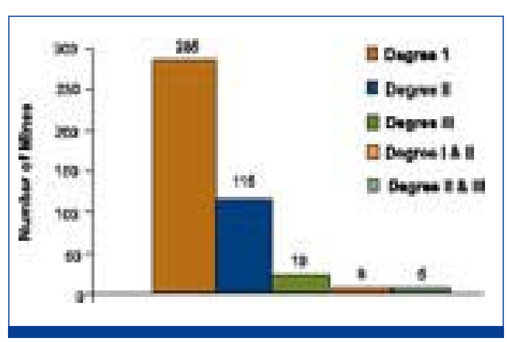


Figure 2.14: Number of mines in India according to their gassiness.

Von Anemometer. The cross-sectional area of each return airway was determined by multiplying the average width and height of the airway. The percentage of methane in the air samples collected in the return airway, and also in the general body air was determined using the Gas Chromatography technique.

An alternative approach was taken to measure the CH_4 emission coefficient from opencast mining. Rectangular chambers were placed on the benches of opencast mines for a pre-determined period of time and methane percentage inside the chamber was determined by Gas Chromatography. The area of coal faces exposed earlier or freshly-exposed were also measured in the opencast mines to calculate methane flux. The emission measurements from post-mining activities were also taken. Also, the emission factors for coal-handling activities were determined for different categories.

Through the above measurements and collection of data on methane emission during mining and post mining activities, emission factors for opencast and under-ground mines were generated for Indian geologic and mining conditions (Table 2.8). Using these emission coefficients, the total CH_4 released in 1994 from Indian coalmines was estimated at 650 Gg.

Table 2.8: CH_4 emission coefficients derived for coal mining in India.

Type of mining	m^3 CH_4 /t coal mined
Underground mining	
During Mining	
degree 1	2.9
degree 2	13.1
degree 3	23.6
Post Mining	
degree 1	1.0
degree 2	2.2
degree 3	3.1
Surface Mining	
During mining	1.8
Post mining	0.2

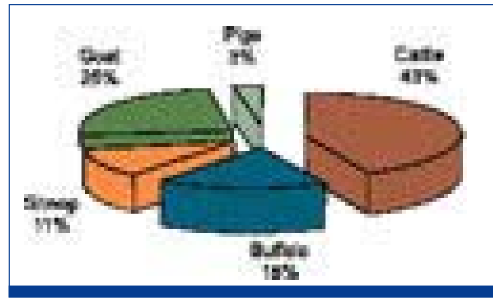
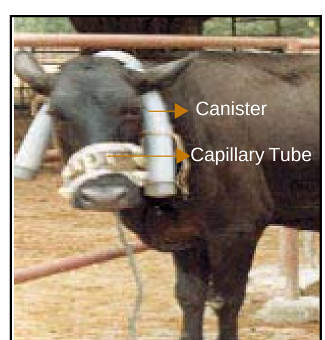


Figure 2.15: Distribution of Indian Livestock.

Agriculture

Enteric fermentation

In India, livestock rearing is an integral part of its culture, as well as for most of the agricultural activities. Although the livestock includes cattle, buffaloes, sheep, goat, pigs, horses, mules, donkeys, camels and poultry, the bovines and the small ruminants are the most dominant feature of Indian agrarian scenario, and the major source of methane emissions (Figure 2.15). Traditional cattle are raised for draught power for agricultural purposes, and cows and buffaloes for milk production. The cattle and buffaloes provide economic stability to farmers in the face of uncertainties associated with farm production in dry land/rain-fed cropped areas. Currently, most of the cattle are low-producing non-descript, indigenous breeds and only a small percentage (5-10 per cent) is of a higher breed (cross-bred and higher indigenous breeds). Even in the case of buffaloes, there are very few high yield animals (10–20 per cent). Sheep rearing is prevalent in many areas because of smaller herd sizes, which are easy to raise and manage,



Methane measurements from enteric fermentation.

providing year-round gainful employment to the small and marginal farmers.

Cattle and buffalo, which are the main milk-producing animals in the country, constitute 61 per cent of the total livestock population in India. The average milk produced by dairy cattle in India is 2.1 kg/day, whereas buffaloes produce 3.5 kg/day (MOA, 2004), which is much less than the milk produced by cattle in the developed countries (IPCC Revised Guidelines, 1996). This is mainly due to the poor quality of feed available to the cattle, specially domesticated in rural households. In spite of the low-energy value of feed intake, CH_4 produced from this source in India is the highest amongst all agricultural sources, contributing about 55 per cent of the total CH_4 emissions. Out of this, the dairy cattle and buffaloes contribute to about 40 per cent.

Considering its key source category status, an attempt was made to estimate as well as measure the CH_4 emission coefficient for cattle. For this purpose, the cattle population has been divided into dairy and non-dairy categories, with sub classification into indigenous and cross-bred types for different age groups (MOA, 1997) (Box 2.3). CH_4 emission coefficients have been determined by three groups. The first is based on the IPCC Tier-II approach, the second on assimilation of published data on methane released from ruminants, and the third is based on a few measurements carried out using the Face Mask Technique as a part of the enabling activities carried out for the preparation of India's Initial National Communication. A summary of the emission factors is given in Table 2.9. It is clear that the indigenous varieties, whether cattle or buffalo have much lower emission coefficients than the cross-bred ones. This is mainly due to the difference in feed intake of the two. By taking a weighted average of emission factors

Box 2.3: Characterization of cattle and buffalo subgroups

Dairy Cattle

- High yield having calves once in a year (cross-bred)
- Low yield having calves once in a year (Indian)

Dairy Buffalo

- Lactating buffalo are classified in a single category i.e., Dairy Buffalo.

Non-dairy

For both Indigenous and Cross-bred cattle and buffalo

- Below one year but more than three months
- One to three years and one to two and a half years for cross-bred
- Adult

Table 2.9: CH_4 emission coefficient adopted for estimating CH_4 emission from Indian livestock

Category	g CH_4 per animal
Dairy cattle	
Indigenous	28±5
Cross-bred	43±5
Non-dairy cattle (indigenous)	
0-1 year	9±3
1-3 year	23±8
Adult	32±6
Non-dairy cattle (cross-bred)	
0-1 year	11±3
1-2 ½ year	26±5
Adult	33± 4
Dairy buffalo	50± 17
Non-dairy Buffalo	
0-1 year	8± 3
1-3 year	22± 6
Adult	44± 11

Collection of CH_4 sample from manure dump site.

produced for the various age categories of cattle and buffalo, the total CH_4 emitted from India due to enteric fermentation is estimated to be 8,972 Gg.

Manure management

The decomposition of organic animal waste in an anaerobic environment produces CH_4 and, therefore, the amount of CH_4 produced depends on how it is managed. The waste produced by non-ruminant animals in India are not collected; however those of cattle and buffalo are used for a variety of purposes. Usually, the waste of cattle is either sun dried as dung cakes for their use in rural cooking, or is stored for use as biogas. The methane produced from such systems is about 946 Gg.

Rice cultivation

Anaerobic decomposition of organic material in flooded rice fields produces CH_4, which escapes into the atmosphere primarily by diffusive transport through the rice plants during the growing season. There are large spatial and temporal variations of methane fluxes which occur due to different soil types, soil organic carbon and various agricultural practices such as choice of water management and cultivar, the application of organic amendments, the mineral fertilizer, and soil organic carbon.

Methane emission measurements from rice cultivation

In India, rice is cultivated under various water management options, depending on the availability of water across the country. In the mountainous regions, rice is grown in terraces created along the side of the mountains. In most of the northern plains and some parts of the eastern region, rice is cultivated by irrigating the fields intermittently or continuously, for a considerable period of time. In other parts of the country, however, rain-fed rice cultivation is predominant where water is only available in the fields during rains. Deep-water rice cultivation, with a water depth ranging from 50-100 cm. is also practiced in the coastal regions of West Bengal and Orissa. Methane flux measurements on a national scale in such representative water regimes have been made since 1991 under various campaigns using the Perspex box technique, whereby samples are collected and analyzed using gas chromatography. India has conducted three to four campaign mode measurements

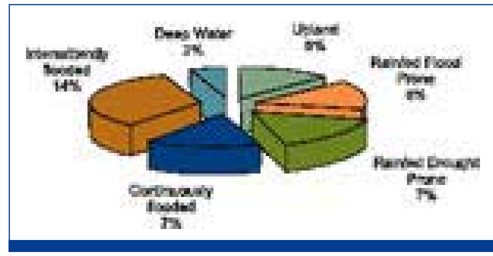


Figure 2.16: Distribution of area under rice cultivation in India.

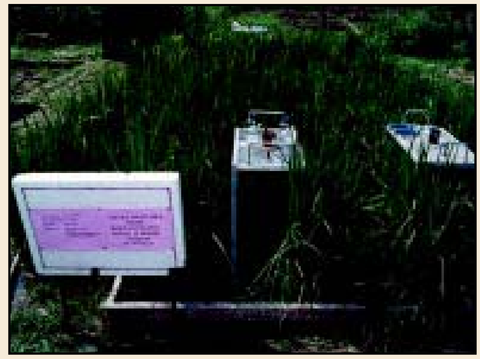
to estimate methane emitted from various water regimes since 1991. The definition of water regimes have changed from campaign to campaign, and finally in 1996 in the IPCC revised guidelines for estimating national GHG emissions from anthropogenic sources. The total area under rice cultivation was categorized under different water regimes, namely, upland, rain fed drought and flood prone, continuously irrigated, irrigation with single or multiple aerations, and deep water (Figure 2.16). Most of these diverse water management systems are also practiced in most traditional rice-producing countries.

The seasonal integrated flux of CH_4 for ecosystems classified according to different water management practices have been averaged and integrated with earlier decadal emission data (measured since 1991) for soils without any organic amendments, and for low soil organic carbon (Box 2.4). Thus, new national methane emission coefficients were generated and is given in Table 2.10 The total CH_4 released from rice cultivation in 1994 is estimated to be 4,090 Gg.

Table 2.10: CH_4 emission coefficient for different water regimes.

Water regime	Emission coefficient (gm^{-2})
Upland	0
Rain fed	
Flood prone	19±6.0
Drought prone	7.0±2.0
Continuously flooded	17.4±4.0
Intermittently flooded	
Single aeration	6.6±1.9
Multiple aeration	2.1±1.5
Deep water	19.0±6.0

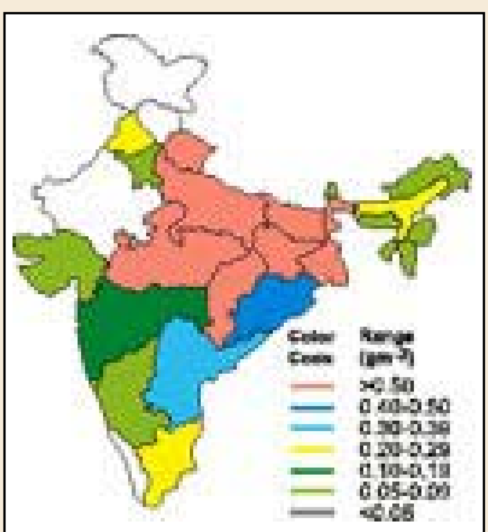
Box 2.4: CH_4 measurement campaign in rice cultivation areas



On site measurement of

Methodologies and types of emission factors used for estimating CH_4 emission from rice fields in India has undergone various changes since the 1st campaign in 1991 was launched to measure the CH_4 fluxes from this source. Based on the 1991 campaign observations, a CH_4 budget estimate was made for rain fed water logged areas, in the eastern, southern, northern and western region of India, the rest of the area was divided as deep water, irrigated and upland area. The emission factor was seasonally integrated over the entire cropping period. The 1995 IPCC guidelines indicated only three regimes namely, upland, intermittently flooded and upland rice. The emission factors were in terms of kg CH_4/ha/day. These water regimes were insufficient for representing the diverse water regimes prevalent in India and other south Asian countries. The revised IPCC guidelines (IPCC, 1996) had a much more detailed water regime consisting of upland and low land conditions, with low land further divided into rain-fed, irrigated and deep-water conditions. Each of these is again subdivided to represent the entire gamut of water flooding conditions in this region.

Methane measurement campaigns have been carried out in India since 1991, and also under the aegis of India's Initial National Communication. The present campaign covered the rice growing regions of West Bengal, Orissa, Assam, Jharkhand, Tamil Nadu, Kerala, Andhra Pradesh and Delhi was made for Rabi 2002 and Kharif of 2003. Other than the water regime, the parameters that have been taken into account are the fertilizer doses, different rice cultivars, soil types, different soil organic carbon and different organic amendments applied.



State-wise distribution of emission coefficients determined through 2002-2003 CH_4 measurement campaign.

A static box or chamber technique was used at all sites over the entire paddy cropping seasons including fallow periods. Flux measurements were made, in the forenoon and afternoon on the same site twice a week. To reduce uncertainties in spatial variability within the cropping field, measurements using four channels/chambers for sampling were used. Samples at all sites were collected in glass vials or plastic syringes manually and CH_4 concentrations in the samples were determined using Gas chromatograph with flame ionization detector (FID) system and GC-Electron capture detector (ECD) respectively. All samples were calibrated against nationally/ internationally comparable standards and proficiency testing for methane were also carried out. The seasonally integrated flux (E_{sif}) were calculated by taking the daily mean of the flux data and integrating it over the whole cropping season from transplantation to harvest stage. Standard deviations from the daily mean flux were used to derive the minimum and maximum ranges of E_{sif}.

Burning of Agricultural crop residue

The burning of crop residue is not a net source of CO_2 as the CO_2 released into the atmosphere during burning is reabsorbed during the next growing season. However, burning of crop residue is a significant net source of CH_4 in addition to other trace gases. The amount of agricultural waste produced by a country depends on its crop management system. In India, the primary end-uses of crop residue are as animal fodder, industrial and domestic fuel, thatching, packaging, bedding, construction of walls/fences, and as green-manure and compost. The amount left is what is available for field burning, and only a fraction of this amount is actually subject to burning. This fraction is, in fact, highly uncertain and varies with local and regional climate, season, livestock distribution, availability of fuelwood, availability of fodder, weed infestation etc.

The crop residue is particularly burnt in the rice/ wheat growing regions of Punjab, Haryana, Uttaranchal, western Uttar Pradesh and Karnataka, where with the introduction of mechanized harvesters, the collection and disposal of residues is a practical problem. Consequently, farmers prefer to burn residues in the field, primarily to clear the remaining straw and stubble after the harvest and to prepare the field for the next cropping cycle. Currently, wastes from nine crops viz., rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut, are subjected to burning. Thus, the total dry residue generation in the year 1994 was estimated to be about 203 thousand tonnes. Using IPCC emission coefficients, the CH_4 released from this source was found to be about 167 Gg.

Field measurements for GHG emissions from agriculture crop residue burning.

Municipal Solid waste management

Solid waste disposal in India takes place in two distinctively different ways. In rural areas and small towns, there is no systematic collection of waste and it is haphazard. As anaerobic conditions do not develop, no methane is generated in these areas. However, in urban towns, solid waste is disposed by land filling in low-lying areas located in and around the urban centres. Due to stacking of waste over the years, anaerobic conditions develop, and hence these dumping sites generate large quantities of biogas containing a sizeable proportion of methane. Based on secondary data on the type of solid waste produced, per capita waste produced, and the Bio-chemical Oxygen Demand (BOD) content of the waste, it is estimated that in 1994, 582 Gg of CH_4 was emitted from this source.

The per capita waste generation will require to be investigated further in the future, by carrying out

A municipal solid waste dumping site in New Delhi.

surveys in individual households in urban areas. It is necessary, that instead of applying a single value of per capita waste generation, which is averaged over highly varying values across the country, a town-by-town value should be developed and applied to reduce the uncertainty in CH_4 emission estimates from this sector. Also, it is expected that with the rapid development that India is presently experiencing, a greater number of small towns will have the facility of disposing their solid waste systematically and consequently, CH_4 emissions from this source may rise significantly in the future.

Waste water management

Domestic and industrial

The Central Pollution Control Board systematically collects data on industrial waste water and domestic waste water generation from big cities (CPCB, 1997). The amount of waste water generated in India in the domestic sector is around 135 litres per capita per day, of which industrial waste water produced for the same period is around 8 per cent of this. The total CH_4 emitted from the management of domestic as well as industrial wastewater in 1994 is estimated to be 421 Gg.

Other sectors

Methane is also produced from other sectors, such as emission from mobile sources, handling and flaring of oil and natural gas, and from industrial sources. In 1994, the amount of CH_4 emitted from the transport sector was about 9 Gg, which is only 0.2 per cent of the total CH_4 emitted from this sector. The flaring and handling of oil and natural gas systems in 1994 led to an emission of 601 Gg. This includes emission due to drilling for oil and natural gas, transport of oil and natural gas, and flaring of natural gas. In the industrial process sector, only the production of black carbon and styrene resulted in an emission of 2 Gg methane

Nitrous Oxide (N_2O) emissions

Nitrous oxide is a GHG, which is produced both naturally, from a wide variety of biological sources like soil and water, and anthropogenically by activities such as agriculture, transport, industrial and waste management sectors. The total N_2O emissions in India in 1994 were 178 Gg, which is only 4 per cent of the total GHG emissions from the country. Agriculture sector accounted for 85 per cent of total N_2O emission from India in 1994, fuel combustion accounted for 6 per cent, industrial processes for 5 per cent, waste for 4 per cent and N_2O emissions from biomass burning was miniscule (Figure 2.17). The sectoral emissions are also detailed in Table 2.11.

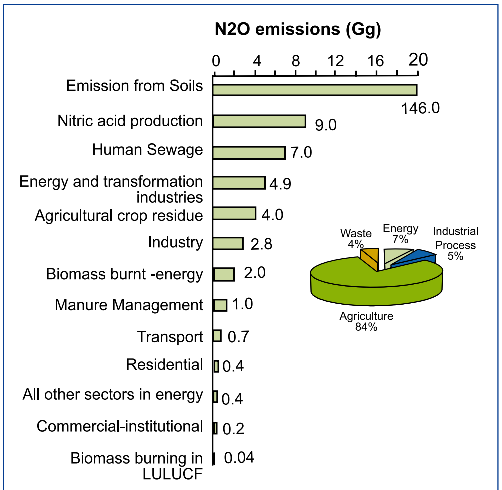


Figure 2.17: Distribution of N_2O emission across sectors.

High degrees of uncertainties are associated with N_2O emission estimates, as most of the activity data, especially in the agricultural sectors are dispersed organic sources that have not been very well quantified. Extensive surveys are required to quantify this data such as the determination of agricultural crop residue burnt on fields and direct and indirect activities leading to N_2O emissions from soil . Since N_2O emission from soils has proved to be a key source of emission in India, it is necessary to develop appropriate emission coefficients through measurements covering the different seasons in the diverse cropping systems of the country.

Fuel combustion

N_2O is a product of the reaction between nitrogen and oxygen during fuel combustion. Both mobile and stationary combustion lead to the emission of N_2O. The quantity emitted varies with type of fuel, technology, pollution control devices used and

Table 2.11: N_2O emission in 1994.

Total (Net) National Emission (Gg per year)	178
1. All Energy	**11.4**
Fuel combustion	
Energy and transformation industries	4.9
Industry	2.8
Transport	0.7
Commercial-institutional	0.2
Residential	0.4
All other sectors	0.4
Biomass burnt for energy	2.0
2. Industrial Processes	**9.0**
Nitric acid production	9.0
3. Agriculture	**151**
Manure management	1
Agricultural crop residue	4
Emission from soils	146
4. Land use, Land-use change and Forestry	**0.044**
Trace gases from biomass burning	0.044
5. Waste	**7.0**
Human sewage	7.0

maintenance and operation practices. For example, catalytic converters installed in motor vehicles to reduce pollution can lead to the formation of N_2O.

In 1994, the N_2O emission from all energy activities accounted for 5 per cent of the total N_2O emissions from India. It includes stationary combustion emissions due to fuel combustion in energy and transformation activities, industry, residential and commercial end uses, biomass burning and emission from mobile sources. Nitrous Oxide emissions from stationary combustion were 11.4 Gg, and from mobile sources about 0.7 Gg.

Nitric acid production

Nitric acid is primarily used as raw material in fertilizer production, and in the production of adipic acid and explosives. It is produced on an industrial scale by the catalytic oxidation of ammonia (Exxon Process) in the presence of air over the precious metals catalysts, for example, platinum, rhodium, and palladium at high temperature and high pressure. During the production of nitric acid (HNO_3), nitrous oxide is produced as a by-product. In the absence of abatement measures, HNO_3 production contributes large amounts of atmospheric N_2O. The worldwide HNO_3 production contributes about 0.4 Tg of N_2O to the atmosphere.

The IPCC default N_2O emission coefficients do not adequately represent the Indian conditions for production of HNO_3. Therefore, attempts were made to conduct real-time measurements of the N_2O concentrations in the tail (stack) gas of different plants operating at medium pressure at 2.5 to 4.5 bar pressure, high pressure at 6 to 12 bar pressure, and dual pressure process in which the reaction was observed at medium pressure and absorption at high pressure. The technologies employed for N_2O abatement are extended absorption, selective catalytic reduction (SCR), and non-selective catalytic reduction (NSCR). The 'NIOSH Method 6600' method was employed for the analysis of N_2O, which is a standard validated method for real-time analysis.

N_2O produced in a medium pressure plant was in the range 6.48 – 13.79 kg per tonne of HNO_3; the mean value was 10.13 kg N_2O per tonne of HNO_3 with an average uncertainty 36.0 per cent. Whereas, N_2O produced in a high pressure plant was in the range 1.54 – 4.13 kg N_2O per tonne of HNO_3; the mean value was 2.84 kg of N_2O per tonne of acid with an average uncertainty of 45.6 per cent. The high pressure plant with NSCR produced the lowest amounts of N_2O, which was in the range 0.24 – 0.57 kg per tonne of HNO_3 with a mean value 0.405 kg N_2O per tonne of acid and 41.0 per cent average uncertainty (Box 2.5). Based on these, N_2O emitted from this source was estimated at 9 Gg in 1994.

Agriculture

Manure Management

During the storage of manure, some of the nitrogen in the manure is converted into N_2O. Nitrous oxide is formed when manure nitrogen is nitrified or denitrified in animals themselves, in animal wastes during storage and treatment, and due to dung and urine deposited by free-range grazing animals. N_2O emission emitted directly from animals is not reported here. There are several animal waste management systems (AWMS) considered here which include

Box 2.5: Determination of N_2O emission coefficient from Nitric acid production

The plants in India are classified into three technology clusters:

- medium pressure process plants (MPP) operating at 2.5 to 4.5 bar pressure,
- high pressure process plants (HPP) operating at 6 to 12 bar pressure, and
- dual pressure process (there was only one plant) i.e., reaction at medium pressure and absorption at high pressure.

The technologies employed for NO_X abatement are extended absorption, selective catalytic reduction (SCR), and non-selective catalytic reduction (NSCR). In India, there are two HPP plants without SCR or NSCR, one HPP plant with NSCR, and one HPP plant with SCR. The remaining plants are based on MPP with extended absorption with or without SCR. Nitric acid is produced as by product in two plants, which have NSCR abatement technology.

The real time measurements of the N_2O concentration in the tail (stack) gas were made at selected nitric acid production plants which are normally operated near 100 per cent capacity as the start up and shut down periods are small. The plants were selected to cover, as far as possible, the full spectrum of nitric acid production technologies being currently used in India.

The concentration of N_2O in the tail gas was measured, at a fixed frequency of 1 or 2 minutes and for varied periods of 0.5 hr to 24 hrs depending on the circumstances. The above sample size was adequate for the statistical evaluation of various parameters.

anaerobic lagoons, liquid systems, daily spread, solid storage and dry lot, pasture range and paddock, used for fuel and other systems. However, care has been taken to avoid including of emissions from stable manure that is applied to agricultural soils (for example, daily spread), dung and urine deposited by grazing animals on fields (pasture range and paddock), from solid storage and dry lot, which are considered to be from agricultural soil and emission from manure used for fuel, which are reported under the energy sector. Using IPCC default values of N_2O emission coefficients for all the activities in this sector, the total N_2O emission in 1994 was 1 Gg.

Emission from soils

This is the largest source of N_2O emission in India, constituting about 81 per cent of the total N_2O in terms of CO_2 equivalent released in 1994. The emission of N_2O results from anthropogenic nitrogen input through direct and indirect pathways, including the volatilization losses from synthetic fertilizer and animal manure application, leaching and run-off from applied nitrogen to aquatic systems. The applied nitrogen includes synthetic fertilizer, animal manure and also the sewage sludge applied to soils. The volatilization of applied nitrogen as ammonia (NH_3) and oxides of nitrogen (NO_x) is followed by deposition as ammonium (NH_4) and oxides of nitrogen (NO_x) on soils and water and accounts for indirect NO_2 emissions from soils. Using the 1996 IPCC methodology and default emission coefficients, the total emission from this source is estimated to be 146 Gg. Although the IPCC default emission factors have been used in the present exercise, large uncertainties still exist in the various

Soil emissions are the largest source of N_2O emissions in India.

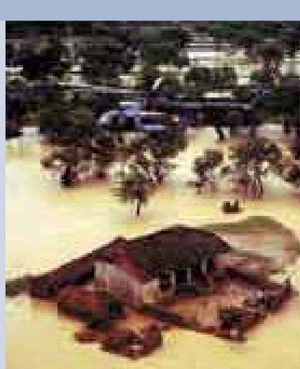
activities associated with the release of N_2O from this source. Therefore, in future, initiatives need to be taken to measure/estimate the respective emission coefficients.

Other sources

Other sources include N_2O emissions from burning of crop residue, and emissions from human sewage in waste water treatment systems. N_2O emitted from burning of crop residue was 4 Gg and from human sewage treatment, it was 7 Gg in 1994.

Chapter 3

Vulnerability Assessment and Adaptation



Vulnerability Assessment and Adaptation

Chapter 3

Climate change is not only a major global environmental problem, but is also an issue of great concern to a developing country like India. The earth's climate has demonstrably changed on both global and regional scales since the pre-industrial era, with some of these changes attributable to human activities. The changes observed in the regional climate have already affected many of the physical and biological systems and there are indications that social and economic systems have also been affected. Climate change is likely to threaten food production, increase water stress and decrease its availability, result in sea-level rise that could flood crop fields and coastal settlements, and increase the occurrence of diseases, such as malaria. Given the lack of resources, and access to technology and finances, developing countries such as India have limited capacity to develop and adopt strategies to reduce their vulnerability to changes in climate.

Article 2 of the UNFCCC refers to the dangerous human influences on climate, in terms of whether they would allow ecosystems to adapt, ensure that food production is not threatened and chart a path of sustainable economic development. Global, national and local level measures are needed to combat the adverse impacts of climate change induced damages.

India is a large developing country with a population of over one billion, whose growth is projected to continue in the coming decades. In India, nearly two-thirds of the population is rural, whose dependence on climate-sensitive natural resources is very high. Its rural populations depend largely on the agriculture sector, followed by forests and fisheries for their livelihood. Indian agriculture is monsoon dependent, with over 60 per cent of the crop area under rainfed agriculture that is highly vulnerable to climate variability and change.

An assessment of the impact of projected climate change on natural and socio-economic systems is central to the whole issue of climate change. Climate change impact assessment involves the following:

- To identify, analyze and evaluate the impact of climate variability and change on natural ecosystems, socio-economic systems and human health.
- To assess the vulnerabilities, which also depend on the institutional and financial capacities of the affected communities, such as farmers, forest dwellers and fishermen.
- To assess the potential adaptation responses.
- To develop technical, institutional and financial strategies to reduce the vulnerability of the ecosystems and populations.

Developing countries such as India have low adaptive capacity to withstand the adverse impacts of climate change due to the high dependence of a majority of the population on climate-sensitive sectors, such as agriculture, forestry and fisheries, coupled with poor infrastructure facilities, weak institutional mechanisms and lack of financial resources. India is therefore, seriously concerned with the possible impacts of climate change, such as:

- Water stress and reduction in the availability of fresh water due to potential decline in rainfall.
- Threats to agriculture and food security, since agriculture is monsoon dependent and rainfed agriculture dominates in many states.
- Shifts in area and boundary of different forest types and threats to biodiversity with adverse implications for forest-dependent communities.
- Adverse impact on natural ecosystems, such as wetlands, mangroves and coral reefs, grasslands and mountain ecosystems.
- Adverse impact of sea-level rise on coastal

agriculture and settlements.

- Impact on human health due to the increase in vector and water-borne diseases, such as malaria.
- Increased energy requirements and impact on climate-sensitive industry and infrastructure.

The assessment of climate change impacts, and vulnerability and adaptation to climate change, require a wide range of physical, biological and socio-economic models, methods, tools and data. The methods for assessing the vulnerability, impact and adaptation are gradually improving, but are still inadequate to help policy-makers formulate appropriate adaptation measures. This is due to uncertainties in regional climate projections, unpredictable response of natural and socio-economic systems and the inability to foresee future technological developments. See Box 3.1 for definitions of vulnerability, adaptability and adaptive capacity.

In this assessment, the vulnerability of natural ecosystems and socio-economic systems, and the impacts of climate change on them are presented. The sectors considered for the assessment of climate change impacts include water resources, agriculture, forest and natural ecosystems, coastal zones, health, energy and infrastructure. First, the climate change projections for the Indian subcontinent are presented. Second, the impact and vulnerability of different sectors are assessed that includes the current status of the sector, impact of climate change, and socio-economic implications of these impacts. Third, adaptation strategies are suggested, along with the current policies and their implications for the vulnerability of the different sectors. Finally, the barriers to adaptation followed by examples of potential technical, institutional and financial strategies to reduce the vulnerability of natural and human systems are presented.

CURRENT CLIMATE AND ITS VARIABILITY IN INDIA

India is subject to a wide range of climatic conditions from the freezing Himalayan winters in the north to the tropical climate of the southern peninsula, from the damp, rainy climate in the north-east to the arid Great Indian Desert in the north-west, and from the marine climates of its vast coastline and islands to the dry continental climate in the interior. The most important feature in the meteorology of the Indian subcontinent and, hence, its economy, is the Indian summer monsoon. Almost all regions of the country receive their entire annual rainfall during the summer monsoon (also called the SW monsoon), while some parts of the south-eastern states also receive rainfall during early winter from the north-east monsoon. Rainfall increases by almost three orders of magnitude from west to east across the country.

The Monsoon

The monsoon is associated with the seasonal heating of the landmasses of Asia in summer and cooling in

Box 3.1: Definitions of Vulnerability, Adaptability and Adaptive Capacity

Vulnerability is the degree to which a system will respond to a given change in climate, including beneficial and harmful effects (IPCC Working Group II, 2001).

Vulnerability is the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change including climate variability and extremes.

Vulnerability is also a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity [Summary for Policy Makers (IPCC Working Group II)].

Adaptability refers to the degree to which adjustments are possible in practices, processes, structures of systems to projected or actual changes of climate. Adaptation can be spontaneous, or planned, and can be carried out in response to or in anticipation of changes in conditions (IPCC, 1996).

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities or to cope with the consequences [Summary for Policy Makers (IPCC Working Group II)].

winter, compared to the waters of the Indian Ocean and the China Seas. While the Indian summer monsoon is a consequence of the thermal differences between the land and the sea in general terms, it is primarily due to the seasonal shifting of thermally produced planetary belts of pressure and winds under continental influences. Further aided by complex seasonal changes in the upper-air circulation during summer under the influence of the Central Asian highlands, especially the Tibetan Plateau, favourable conditions are created for the Asian summer monsoon to develop into a powerful air stream. During winter, the presence of an extensive high-pressure area over the cold continent of Central Asia extending into northern India, and low pressure over the Indian Ocean facilitates the flow of air from the north towards the Indian Ocean at lower levels. This flow, in the form of north-easterlies (also known as the north-east monsoon), brings winter rains to the southern parts of India. Apart from the monsoons, the north-western parts of India receive considerable precipitation from the western disturbances. However, for a major part of the country, almost the whole of the annual rainfall is realized during the SW monsoon season, making the people and, hence the economy critically dependent on it.

Rainfall and Surface Temperature Patterns

Rainfall: Meteorological records maintained since the 19th century indicate that the Indian summer monsoon is reasonably stable; however, simultaneous occurrence of devastating floods in some areas and parching droughts in others is a common feature. The interannual variability of the monsoon is the cause of such contrasting features[1] (Figure. 3.1). It has been observed that regions with low seasonal rainfall also experience high variability, making them chronically drought prone. The effect of droughts is further accentuated by the occurrence of two to three consecutive drought years in the same region.

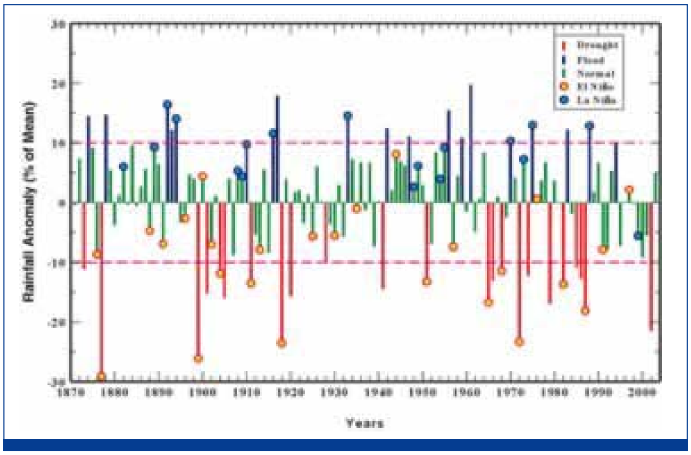


Figure 3.1: Variation of all-India monsoon rainfall during 1871-2001.

The Indian monsoon has a direct link with the Southern Oscillation Index (SOI). Weak Indian monsoons in the country are associated with a large negative SOI and occurrence of *El Niño*. Whereas, strong monsoons have been linked to large positive SOIs and absence of *El Niño* events. Besides these, several global and regional parameters have been found to contribute to the interannual variability of the monsoon rainfall, which form the basis for its seasonal forecasting. However, the relationships between the Indian monsoon and regional/global circulation parameters are known to have undergone significant multi-decadal changes obscuring the causal mechanisms.

Although the monsoon rainfall at the all-India level does not show any trend and seems mainly random in nature over a long period of time, the presence of pockets of significant long-term changes in rainfall have been recorded. Areas of increasing trend in the monsoon seasonal rainfall are found along the west coast, north Andhra Pradesh and north-west India (+10 to +12 per cent of normal/100 years) and those of decreasing trend over east Madhya Pradesh and adjoining areas, north-east India and parts of Gujarat and Kerala (-6 to -8 per cent of normal/100 years) (Figure. 3.2).

[1] A year is classified as deficient, normal (negative), normal (positive) or excess monsoon year, when the all-India summer monsoon rainfall is below -10 per cent, between -10 per cent and zero, between zero and +10 per cent, or above +10 per cent, respectively.

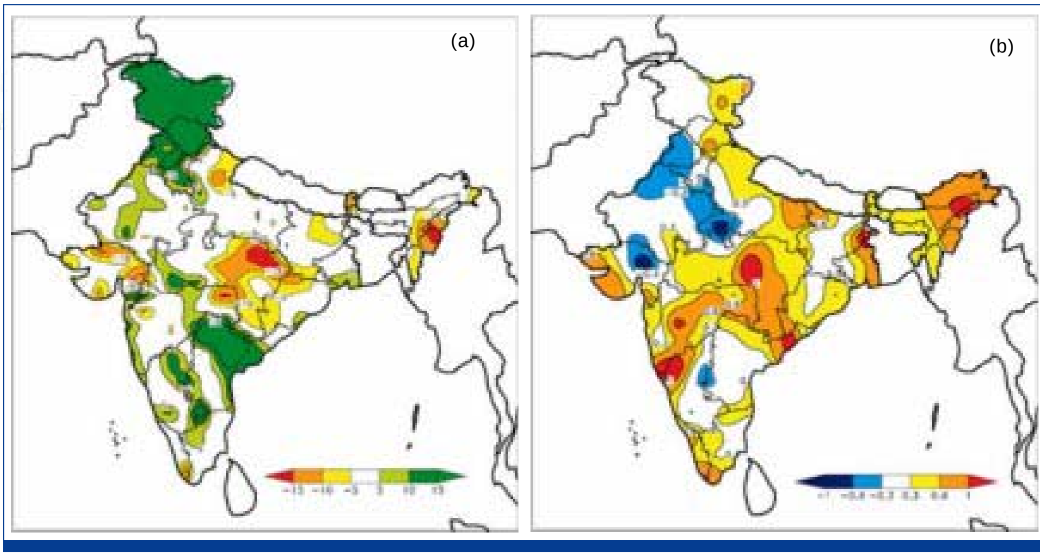


Figure 3.2: Spatial patterns of linear trends (percentageof mean/100 years) in (a) summer monsoon rainfall; and (b) annual mean surface temperature during 1871-1990.

Temperature: All-India and regional mean seasonal and annual surface air temperature for the period 1901-2000 indicate a significant warming of 0.4°C per hundred years. On a seasonal scale, the warming in the annual mean temperatures is mainly contributed by the post-monsoon and winter seasons. Also, data analyzed in terms of daytime and night-time temperatures indicate that the warming was predominantly due to an increase in the maximum temperatures, while the minimum temperatures remained practically constant during the past century. The seasonal/annual mean temperatures during 1901-2000 are based on data from 31 stations, while the annual mean maximum and minimum temperature during 1901-1990 are based on data from 121 stations. Spatially, a significant warming trend has been observed along the west coast, in central India, the interior peninsula and over north-east India, while a cooling trend has been observed in north-west India and a pocket in southern India (Figure 3.2).

Extreme weather and climate events

In India, the climate and weather are dominated by the largest seasonal mode of precipitation in the world, due to the summer monsoon circulation. Over and above this seasonal mode, the precipitation variability has predominant interannual and intra-seasonal components, giving rise to extremes in seasonal anomalies resulting in large-scale droughts and floods, and also short-period precipitation extremes in the form of heavy rainstorms or prolonged breaks on a synoptic scale. Indeed, rainfall during a typical monsoon season is by no means uniformly distributed in time on a regional/local scale, but is marked by a few active spells separated by weak monsoon or break periods of little or no rain. Thus, the daily distribution of rainfall at the local level has important consequences in terms of the occurrence of extremes. Further, the Indian climate is also marked by cold waves during winter in the north, and heat waves during the pre-monsoon season over most parts of the country. Tropical cyclones, affecting the coastal regions through heavy rainfall, high wind speeds and storm surges, often leave behind widespread destruction and loss of life, and constitute a major natural disaster associated with climatic extremes. Indeed, it is these extremes that have the most visible impact on human activities and therefore, receive greater attention by all sections of the society.

Droughts and Floods: It has already been noted that the Indian summer monsoon is a very stable and dependable source of water for the region. Superimposed on this stable picture are seemingly

Box 3.2: Impacts of Droughts and floods in India.

There are four major reasons for droughts in India-delay in the onset of monsoon/ failure of monsoon, variability of monsoon rainfall, long break in monsoon and areal difference in the persistence of monsoon. Almost a quarter of India's land area is prone to drought. Areas that receive up to 60 centimeters of rainfall annually are the most drought prone. The drought is almost directly linked to the areal variation in the monsoon, the effect of which lasts for much longer than the actual span of the monsoon. The most affected community are the marginal farmers dependent on rainfed agriculture.


Droughts affecting marginal farmers.

Compared to drought, a smaller area is affected by large-scale flooding. However the loss in terms of lives and property is much higher. From the approximately 19 Mha affected by floods in India about five decades ago, the figure today stands at about 36 Mha - almost double (CWC,1997). Some of the causes of floods are: Unusually high rainfall in a short period of time, which leads to high volume of run-offs, Rivers or other water bodies overflowing their banks, Excessive deforestation of hills can cause floods lower downstream. Inadequate drainage facilities may cause water to stagnate. Change in the course of rivers and in the coastal regions and tropical cyclones can also cause flooding.


Devastation of crops due to extensive flooding.

small year-to-year changes that can be spatially quite extensive. However, even such small changes constitute significant interannual variability, leading to widespread drought and flood situations. Instrumental records over the past 130 years do not indicate any marked long-term trend in the frequencies of large-scale droughts or floods in the summer monsoon season. The only slow change discernible is the alternating sequence of multi-decadal periods of more frequent droughts, followed by periods of less frequent droughts. This feature is part of the well-known epochal behaviour of the summer monsoon. See Box 3.2 for impacts of floods and droughts in India.

***Aridity*:** There are large tracts in north-western India and the interior peninsula that experience arid conditions. Although desertification is a complex environmental process involving geomorphologic and atmospheric processes, it is observed that the rainfall regimes generally closely demarcate the arid region boundaries. In general, during extreme deficient years of SW monsoon over the Indian subcontinent, aridity takes over the semi-arid areas and its spatial extent continues deep down south to the peninsula. On an average, about 19 per cent of the country experiences arid conditions every year, of which 15 per cent is in northern India and 4 per cent in the peninsula.

Short-duration rainfall extremes: The spatial patterns of the mean annual number of rainy days derived from observed rainfall data are presented in Figure 3.3. A rainy day is defined as a day with a rainfall of 2.5 mm and above, as per the operational practice of the India Meteorological Department (IMD). The mean annual number of rainy days over India varies from less than 20 days over the north-western parts (west Rajasthan and Kutchh region of Gujarat), to more than 180 days in the north-east (Meghalaya). North-eastern India and the southern parts of the west coast are major areas of relatively high mean annual number of rainy days (about 140 days). The mean annual number of rainy days increases from west to east, particularly in the northern parts of the country. Over central parts of India, the number of rainy days is around 40-60 days. Over the west coast, along the tracks of monsoon disturbances and near the foothills of the Himalayas, it is around

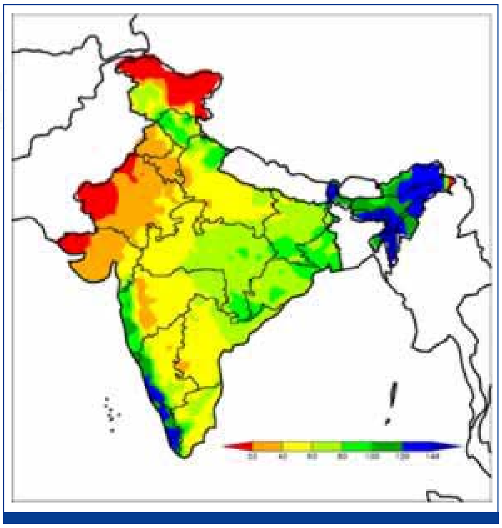


Figure 3.3: Spatial patterns of observed mean annual number of rainy days over India.

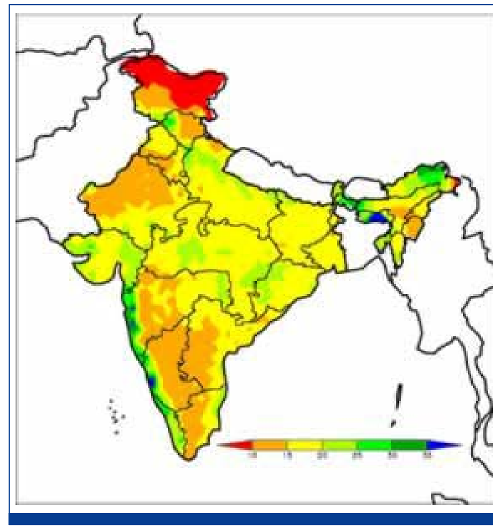


Figure 3.4: Spatial patterns of observed mean intensity of rainfall (mm/day) over India.

80 days. From the observed spatial pattern of the mean intensity of rainfall per rainy day (Figure. 3.4), it is seen that the intensity varies between 10 mm and 40 mm per rainy day over India. The lowest values of less than 10 mm/day occur in the extreme northern parts of the country. Over north-western India and the rain-shadow region to the east of the Western Ghats in the peninsula, the intensity is around 10-15 mm per rainy day. The highest value of about 40 mm/day occurs along the west coast, as well as in some parts of north-eastern India. Over the rest of the country, the intensity of rainfall is of the order of 15-25 mm/day.

Extreme Temperatures: Spatial patterns of observed extreme daily maximum temperatures are shown in Figure 3.5. It has been observed that over the central parts of India, the maximum temperatures recorded exceed 45°C, while along the west coast, the extreme maximum temperatures recorded range between 35°-40°C. Smaller values of extreme maximum temperatures of around 25°C have been recorded in Himachal Pradesh in the north. Figure 3.6 shows the spatial pattern of extreme minimum temperatures, which represent the lowest temperature ever recorded in the respective regions. Low-temperature extremes dropping to less than -15°C have been recorded in the northern most parts of India. Extreme minimum temperatures below 0°C have also been observed in

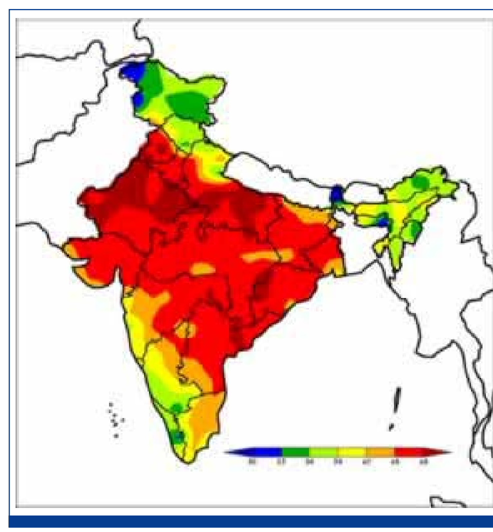


Figure 3.5: Spatial patterns of observed extreme daily maximum temperatures (ºC) over India.

the region north of 25°N and west of 80°E.

Cyclonic storms: In the northern Indian Ocean, about 16 cyclonic disturbances occur each year, of which about six develop into cyclonic storms. The annual number of severe cyclonic storms with hurricane force winds averages to about 1.3 over the period 1891-1990. During the recent period 1965-1990, the number was 2.3. No clear variability pattern appears to be

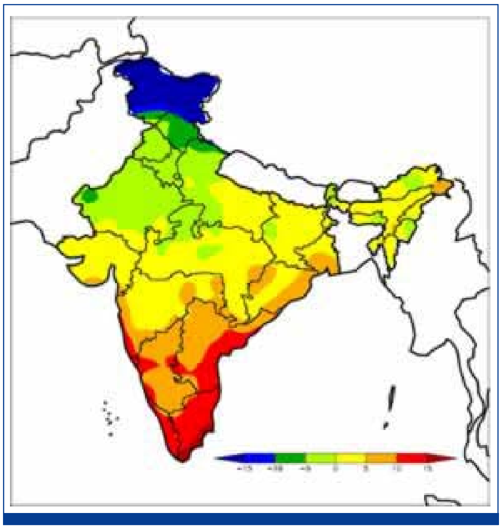


Figure 3.6: Spatial patterns of observed extreme daily minimum temperatures (ºC) over India.

associated with the occurrence of tropical cyclones. While the total frequency of cyclonic storms that form over the Bay of Bengal has remained almost constant over the period 1887-1997, an increase in the frequency of severe cyclonic storms appears to have taken place in recent decades (Figure 3.7). Whether this is real, or a product of recently enhanced monitoring technology is, however, not clear. A slight decreasing trend in the frequency of cyclonic disturbances and tropical cyclones is apparent during the monsoon season. High sea surface temperature is a necessary, though not sufficient, condition for the formation and growth of tropical cyclones. Over the Indian Ocean, Bay of Bengal and the Arabian Sea, significant and consistent warming of the sea surface has occurred during the 20th century. Sensitivity experiments with numerical models suggest that cyclone intensity may increase with the increasing sea surface temperatures.

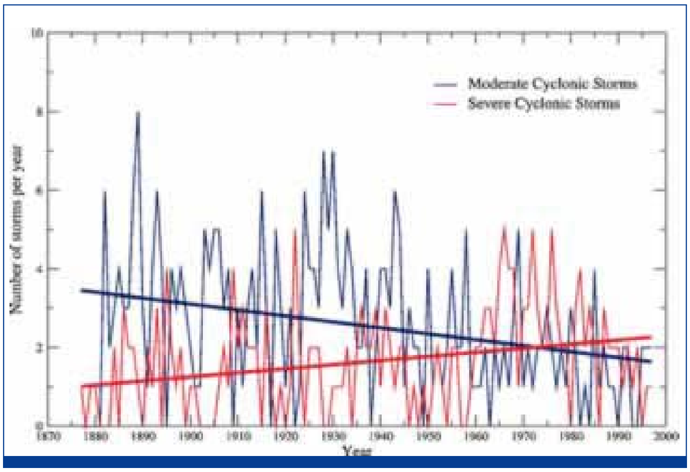


Figure 3.7: Variation of the frequency of moderate and severe cyclonic storms over the Indian seas.

CLIMATE MODEL SIMULATIONS OF THE INDIAN CLIMATE

While most global climate models simulate the general migration of tropical rain belts from the austral summer to the boreal summer, some of them miss the rainfall maximum in the tropical Pacific Ocean. Apart from this, in the Indian monsoon context, the observed maximum rainfall during the monsoon season along the west coast of India, northern Bay of Bengal and adjoining north-east India is not quite realistically simulated in many models. This may possibly be linked to the coarse resolution of the models, as the heavy rainfall over these regions is generally in association with the steep orography. However, the annual cycle in the simulated precipitation over the Indian region (land and sea) comprising 8ºN; 30ºN and 65ºE; 95ºE showed remarkably similar patterns (Figure 3.8). Most models underestimate the rainfall during the rainy season. The simulated annual surface air temperature patterns over the Indian region generally agree with the observed gross features, though magnitudes differ from the observed values in most models. The possible biases associated with the coarse resolution of the Atmosphere-Ocean General Circulation Models (AOGCMs) need to be taken into account while interpreting the future climate change scenarios.

The global atmosphere-ocean coupled models have provided good representations of the planetary scale features, but their application to regional studies is limited by their coarse resolution (~300 km). Developing high resolution models on a global scale is not only computationally prohibitively expensive

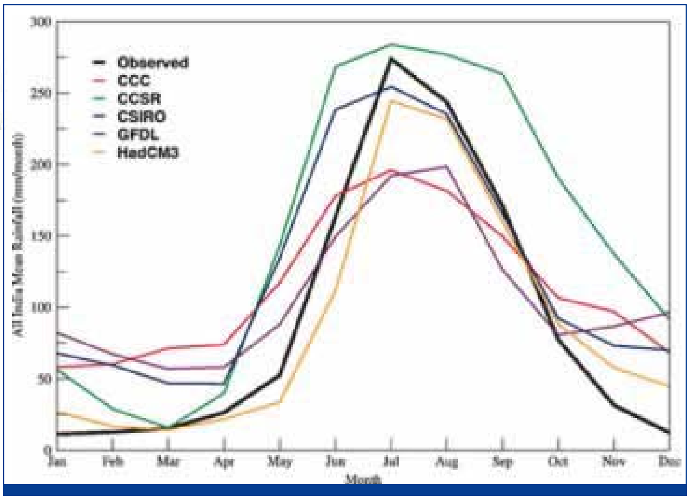


Figure 3.8: Observed and simulated Control (CTL) annual cycles of rainfall over India.

for climate change simulations, but also suffers from errors due to inadequate representation of high-resolution climate processes worldwide. It is in this context that regional climate models (RCMs) provide an opportunity to dynamically downscale global model simulations to superimpose the regional detail of specified regions. As highlighted by Noguer et al. (2002), developing high-resolution climate change scenarios helps in: (a) a realistic simulation of the current climate by taking into account fine-scale features of the terrain, etc.; (b) more detailed predictions of future climate changes, taking into account local features and responses; (c) representation of the smaller islands and their unique features; (d) better simulation and prediction of extreme climatic events; and (e) generation of detailed regional data to drive other region-specific models analyzing local-scale impacts.

In the present assessment, the high-resolution simulations for India based on the second generation Hadley Centre regional climate model (HadRM2) are used. HadRM2 is a high-resolution climate model that covers a limited area of the globe, typically 5,000 km x 5,000 km. The typical horizontal resolution of HadRM2 is 50 km x 50 km. The regional model reproduces large-scale features of the General Circulation Model (GCM) climate and adds realistic local detail. For example, the rain-shadowing effect of the Western Ghats is closer to the observations (Figure 3.9). The annual cycles of rainfall and surface air temperature are also remarkably close to the observed patterns, which demonstrate that the regional model is able to overcome the large biases of the GCM in portraying these features.

In terms of short-duration rainfall, it is observed that the spatial pattern of rainy days is well-generated by the model over the west coast, north-western India and north-eastern India (except for Arunachal Pradesh, where it is overestimated to exceed 180 days). However, the regional model generally underestimates the intensity of rainfall over the country, except for some parts in Himachal Pradesh,

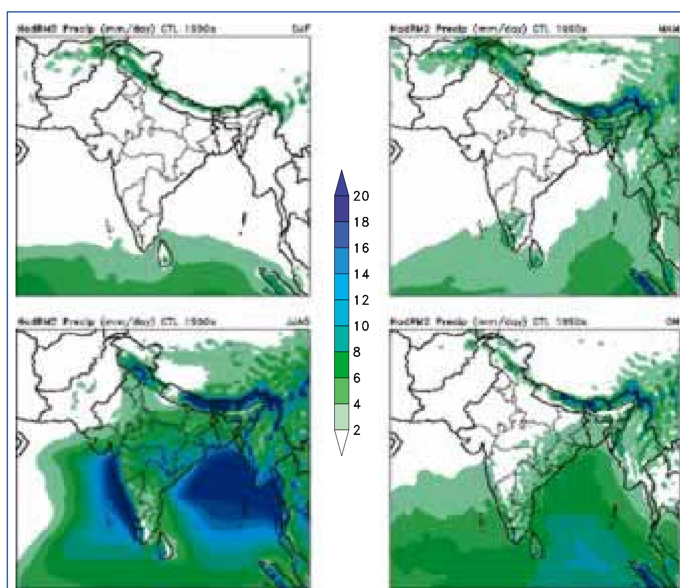


Figure 3.9: Spatial patterns of seasonal rainfall over India as simulated by a regional climate model (HadRM2; CTL).

north-eastern India and along the west coast. While the model represents the spatial variation reasonably well, there is a clear bias in terms of the magnitude, at least by 5 mm per rainy day over a major part of the country. Comparing the spatial pattern of one-day extreme rainfall as generated in control run, it can be concluded that rainfall extremes are reasonably well-simulated by the model in the region south of 20°N, but north of it, the model underestimates the extremes by around 10 cm/day.

Model-simulated data shows a balance between simulated and observed extreme maximum temperatures in the peninsular region. However, the model underestimates high-temperature extremes in the mountainous regions of Kashmir, Sikkim and Arunachal Pradesh, and overestimates the extreme maximum temperature by about 5°C over the northern plains. The patterns of extreme minimum temperatures are well-represented by the model over most of the country, except over some regions in Gujarat, Madhya Pradesh and Bihar, where it underestimates by about 5°C.

CLIMATE PROJECTIONS

Climate projections at the national level

For assessing the nature of the likely future climate in India at an all-India level, eight AOGCMs (Box 3.3) have been run using the IS92a and SRES A2 and B2 scenarios (Box 3.4).

The simulated climate approximately represents the period spanning the nominal time scale of 1860-2099, but the individual model years do not correspond to any specific years or events in this period. Considering all the land-points in India according to the resolution of each AOGCM, the arithmetic averages of rainfall and temperature fields are worked out to generate all-India monthly data for the entire duration of model simulations and for different experiments. This monthly data is then used to compute the seasonal totals/means of rainfall/temperature. Taking 1961-1990 as the baseline period, the seasonal quantities are then converted into anomalies (percentage departures in the case of rainfall). The resulting time series are examined for their likely future changes into the 21st century (Figure 3.10).

Box 3.3. Coupled AOGCM used for deriving climate change projections

- Canadian Center for Climate Modeling, Canada (CCC).
- Center for Climate System Research, Japan (CCSR).
- Commonwealth Scientific and Industrial Research Organization, Australia (CSIRO).
- Deutsches Kilma Rechen Zentrum, Germany (DKRZ).
- Geophysical Fluid Dynamics Laboratory, USA (GFDL).
- Hadley Center for Climate Prediction and Research, UK (HadCM3).
- Max-Planck Institute, Germany (MPI).
- National Center for Atmospheric Research, USA (NCAR).

Box 3.4. Scenarios used in climate model experiments

- ***CTL***: The control integration, in which the atmospheric forcing in terms of the GHG concentration is kept constant, typically at 1990 values, has been performed for a period of over several hundred years in length. The climatology constructed from the CTL run represents the current climate and serves as a reference for all the time-dependent forcing experiments.
- ***IS92a Scenario of GHG increase***: In this experiment, the GHG forcing is increased gradually to represent the observed changes in forcing due to all the GHG from 1860 to 1990. For the future time period 1990-2099, the forcing is increased at a compounded rate of 1 per cent per year (relative to 1990 values), representing the IS92a emissions scenario.
- ***A2 Scenario of SRES (A2):*** A2 scenario falls in the category of 'Medium-High' emissions. The cumulative global carbon emissions between 2000 and 2100 for this scenario is taken to be 1862 GtC (1GtC = 1 giga or Bt of Carbon; 1 tonne of Carbon = 3.67 tonnes of CO_2).
- ***B2 Scenario of SRES (B2):*** B2 scenario falls in the category of 'Medium-Low' emissions.

GHG simulations with IS92a scenarios show marked increase in both rainfall and temperature by the end of the 21st century relative to the baseline. There is a considerable spread among the models in the

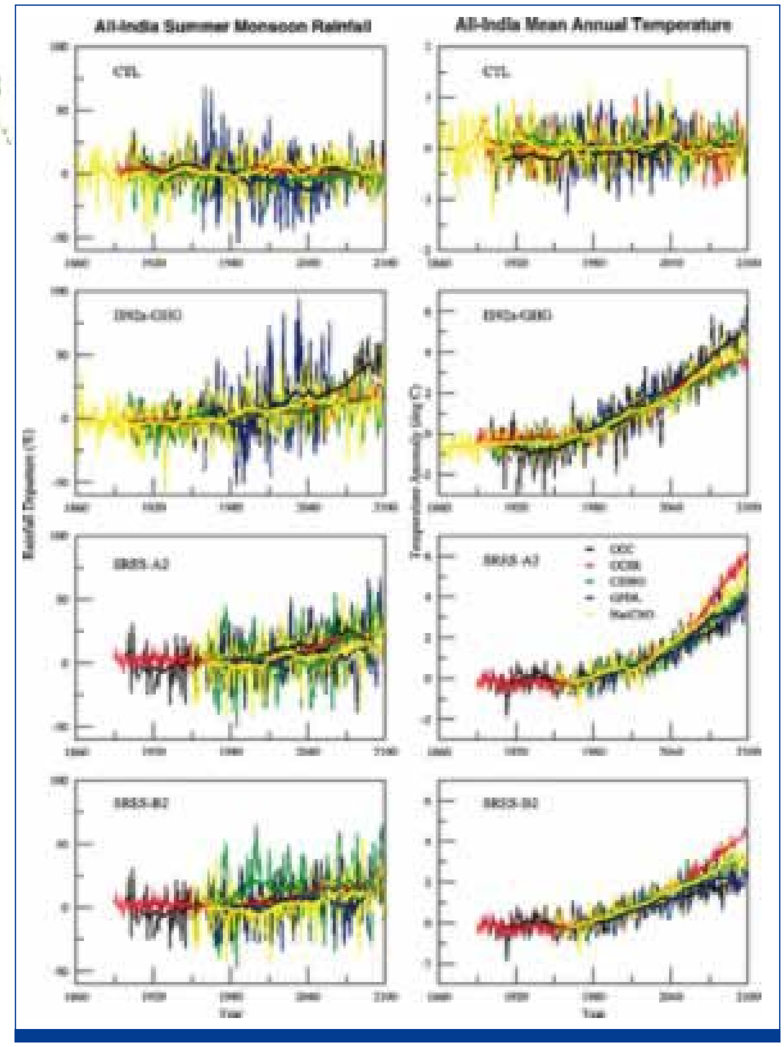


Figure 3.10: AOGCM projections of all-India mean summer monsoon rainfall and annual mean surface air temperature up to the year 2100, for CTL IS92a and SRES A2 and B2 scenarios.

magnitudes of both precipitation and temperature projections, but more conspicuously in the case of summer monsoon rainfall. The increase in rainfall from the baseline period (1961-1990) to the end of the 21st century ranges between 15 per cent and 40 per cent among the models. In the case of mean annual temperature, the increase is of the order of 3ºC to 6ºC. It is apparent that the change in rainfall under A2 and B2 scenarios is not as high as that noted earlier in IS92a scenarios (Figure 3.10). Compared to the A2 scenario, the B2 simulations show subdued trends in the future. The temperature, however, shows comparable increasing trends in IS92a and A2, but B2 shows slightly lower trends.

GCM's project enhanced precipitation during the monsoon season, particularly over the north-western parts of India. However, the magnitudes of projected change differ considerably from one model to the other, when projections of rainfall are considered at state level (Figure 3.11). There is very little or no change noted in the monsoon rainfall over a major part of peninsular India. It is important to note here, that the maximum change in rainfall occurs over the climatologically low rainfall region of north-western India. The implications of such change over this region have to be carefully assessed in future studies. As far as the temperature trends in the future are concerned, all the models show positive trends indicating widespread warming into the future (Figure 3.11). Examination of the spatial patterns of annual temperature changes in the two future time slices for different models indicates that the warming is more pronounced over the northern states of India. The different models/experiments generally indicate the increase of temperature to be of the order of 2-5°C across the country. The warming is generally higher in the IS92a scenario runs compared to A2 and B2 simulations. Also, the warming is more pronounced during winter and post-monsoon months, compared to the rest of the year. Interestingly, this is a conspicuous feature of the observed temperature trends from the instrumental data analyses over India.

Climate Projections at the regional level

To provide a general idea of the scenarios for different states of India, the expected changes in monsoon rainfall and mean annual temperature have been computed for the 2050s (Figure 3.11). It can be seen that there is an all-round increase in temperatures, and a general increase in monsoon precipitation.

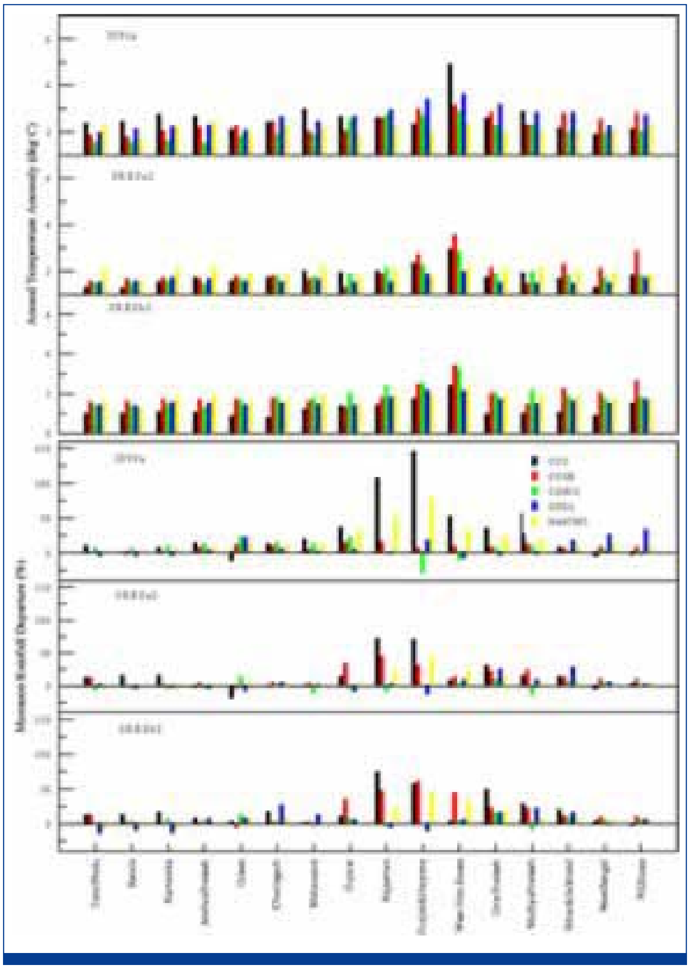


Figure 3.11:. AOGCM-based projections for the 2050s, of summer monsoon rainfall and mean annual temperature of different states of India, relative to the baseline period of 1961-90.

However, there is a large spatial variation in the relative increase in monsoon precipitation, obviously due to the climatological patterns of rainfall.

It must be mentioned here that these scenarios are based on very coarse resolution global climate models, and the values for the smaller states are based on one or two grid points and therefore, may be subject to large biases related to orography and other local characteristics. To overcome this limitation, it is useful to consider the projections based on high-resolution regional climate models. Work on this aspect is in progress, but some preliminary scenarios based on HadRM2, for the IS92a scenario for the future time slice of 2041-2060 may be considered here. In the regional climate model, under increasing atmospheric GHG concentrations, the mean surface temperatures are seen to increase everywhere in the region, in all the seasons (Figure 3.12). The warming is more pronounced over land areas, with the maximum increase over northern India. The warming is also relatively greater in winter and post-monsoon seasons. The summer monsoon season is marked by a relatively lower magnitude of warming. This seasonal asymmetry of greenhouse warming over India has a remarkable resemblance to that seen in the case of observed trends in all-India mean surface temperatures over the past century. However, the spatial patterns of warming during the monsoon season indicate that the maximum warming occurs over northern India, with a secondary maximum over the eastern peninsula.

Regarding the precipitation response, the monsoon season is of prime importance, given the region's critical dependence on summer monsoon rainfall. In this season, the precipitation response is more variable with a decrease seen over the land towards the west and increase over the Indian Ocean. The central and the eastern regions of the country do not show much variability with respect to the control runs (Figure 3.13). In general, on an annual scale, large decreases are seen over the western part of India mainly over the oceanic areas, and increases over the north-eastern parts of the country. These differences in future rainfall change patterns in HadRM2, compared to the AOGCMs, are possibly related to the use of the Hadley Center Model (HadCM2) projections to drive the HadRM2. Significant differences have been noted in the future rainfall change patterns between HadCM2 and

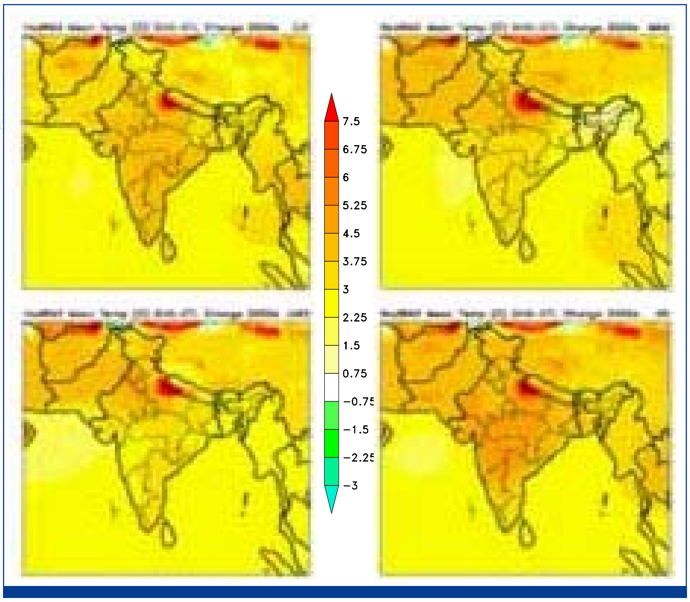


Figure 3.12:. Projections of seasonal surface air temperature for the period 2041-2060, based on the regional climate model HadRM2.

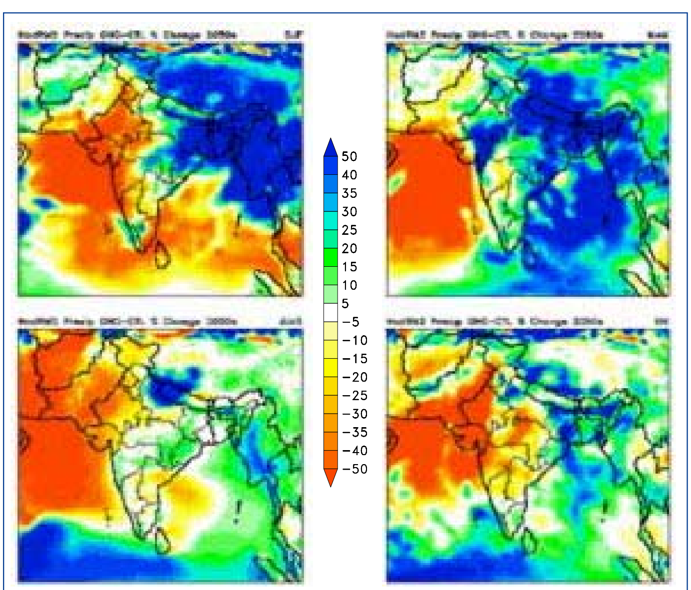


Figure 3.13:. Projections of seasonal precipitation for the period 2041-2060, based on the regional climate model HadRM2.

HadCM3. While HadCM2 shows a tendency for reduced rainfall over India, HadCM3 shows increased rainfall into the 21st century. Further work using more recent versions of the regional model as well as its boundary forcing is in progress to reduce such uncertainties.

Projections of extremes in rainfall and temperature

Keeping in view the need to analyze the changes on a smaller space-time scale to derive information related to the extremes, only regional climate model results are discussed here. HadRM2 is more reliable in representing the observed patterns of extremes in rainfall and temperature. Considering the control run of the model as the baseline Climatology representing the present day conditions, the future scenarios representing the 2050s, under the IS92a scenario of GHG emissions, are derived. In the IS92a scenario, the model showed an overall decrease in the number of rainy days over a major part of the country (Figure 3.14). This decrease is more in western and central parts of the country (by more than 15 days) while along the foothills of Himalayas (Uttaranchal) and in north-east India the number of rainy days is found to increase by 5-10 days. An increase in GHG concentrations may lead to overall increase in the rainy day intensity by 1-4 mm/day, except for small areas in north-western India, where the rainfall intensities decrease by 1 mm/day (Figure 3.15). The model results also indicate that there will be an overall increase in the highest one-day rainfall over a major part of the Indian region. This increase may be up to 20 cm/day. However, in some parts of north-western India, a decrease in extreme rainfall up to about 10 cm/day has been noticed in the GHG experiment.

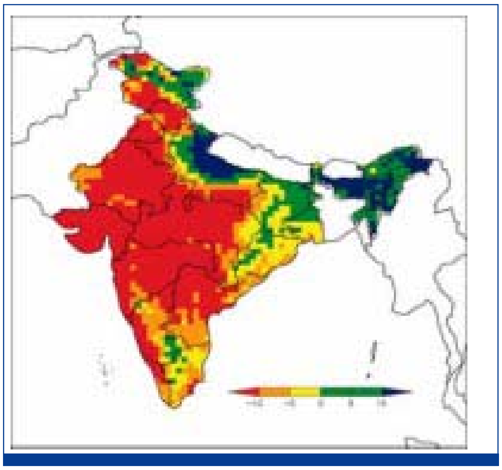


Figure 3.14: Projections of mean incremental annual number of rainy days for the period 2041-2060, based on the regional climate model HadRM2.

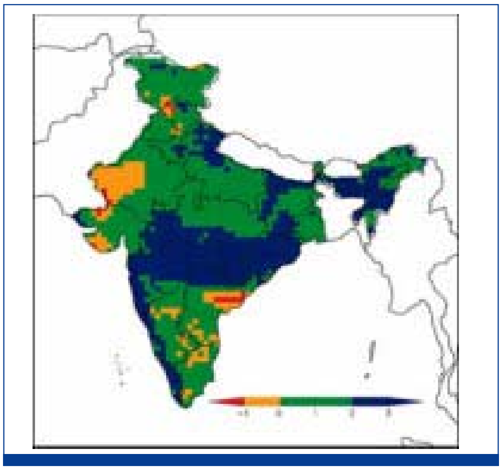


Figure 3.15: Projections of mean incremental rainy day intensity (mm/day) for the period 2041-2060, based on the regional climate model HadRM2.

Summary

The regional model (HadRM2, IS92a scenario) is able to overcome the large biases of the GCM in portraying the annual cycles of rainfall and surface air temperature. The projections of climate variables for the 2050s, under the IS92a scenario of GHG emissions are summarized below;

- An all-round increase in temperatures, and a general increase in monsoon precipitation in the monsoon season. The precipitation response is more variable with a decrease over the land towards the west and an increase over the Indian Ocean.
- A large spatial variation in the relative increase in monsoon precipitation
- An overall decrease in the number of rainy days over a major part of the country
- An overall increase in the rainy day intensity by 1-4 mm/day
- An increase in the temperature (maximum and minimum) of the order of 2-4°C over the southern region which may exceed 4°C over the northern region

Uncertainties in prediction: Regionally, there are large differences among different GCMs, especially in precipitation-change patterns over the Indian subcontinent. Most GCM models project enhanced precipitation during the monsoon season, particularly over the north-western parts of India. However, the magnitudes of projected change differ considerably from one model to the other. Uncertainties exist in the projections of climate models specifically concerning their spatial resolutions. The GCMs are robust in projecting temperature changes rather than rainfall changes. Regional climate models also have large uncertainty (rainfall projection using HadRM2 versus HadRM3), but are still evolving. It is expected that uncertainty would reduce as the regional climate models evolve. Thus, caution must be exercised when using climate projections, though there is a robust projection of significant warming.

Climate Change Scenario Links to other Sectors: According to the Second and Third Assessment Report of the IPCC at the global and continental level, the projected climate change is likely to impact the natural ecosystems and socio-economic systems Under the National Communications project the impacts of projected climate change are analyzed for different sectors in the following sections. The assessment of climate change impacts are made using RCM projections for some sectors (for example, water resources and forest ecosystems). The impacts, vulnerability and adaptation options are presented for different sectors in the following sections.

CLIMATE CHANGE IMPACTS ON WATER RESOURCES

Present Indian Water Resources Scenario

India is a land of many rivers and mountains. Its geographical area of 328.726 Mha is covered by a large number of small and big rivers. Over 70 per cent of India's population of one billion is rural and agriculturally oriented, for whom these rivers are the source of their livelihood and prosperity.

Climate plays a very decisive factor in water resource availability of a country. Rainfall in India is mainly dependent on the SW monsoon between June to September, and the north-east monsoon between October and November. The variations in temperature are also marked over the Indian subcontinent. During the winter season from November to February, the temperature decreases from south to north due to the effect of continental winds over most of the country. Evapotranspiration rates closely follow the climatic seasons, and reach their peak in the summer months of April and May. The central areas of the country display the highest evapotranspiration rates during this period. After the onset of monsoon, potential evapotranspiration decreases generally all over the country.

There are 12 major rivers in India (with individual catchment areas of more than 10 Mha), with a cumulative catchment area of 252.8 Mha. Of the major rivers, the Ganga-Brahmaputra-Meghna system is the largest, with a catchment area of about 110 Mha, that is more than 43 per cent of the cumulative catchment area of all the major rivers in the country. This river system is the major contributor to the surface water resources potential of the country. Its share is about 60 per cent of the total water resource potential of the various rivers.

The other major rivers with a catchment area of more than 10 Mha each are the Indus (32.1 Mha); Godavari (31.3 Mha); Krishna (25.9 Mha); and the Mahanadi (14.2 Mha). The total catchment area of medium rivers is about 25 Mha and Subernarekha, with a 1.9 Mha catchment area, is the largest river amongst the medium rivers in the country.

The annual precipitation, including snowfall, which is the main source of the water in the country, is estimated to be of the order of 4'000 km^3. There are 35 meteorological sub-divisions with respect to the rainfall variability. The water resources potential of the country (occurring as natural run-off in the rivers) is about 1,869 km^3, as per the latest basin-wise estimates made by the Central Water Commission. While India is considered rich in terms of annual rainfall and total water resources, its uneven geographical distribution causes severe regional and temporal shortages.

Water Demand: Water is the most critical component of life support systems. India shares about 16 per cent of the global population but it has only 4 per cent of the total water resource. The irrigation sector with 83 per cent of use is the main consumer of water. Based on the 1991 Census, the per capita availability of water works out to 1,967 m^3. Due to various constraints of topography, and uneven distribution of resources over space and time, it has been estimated that only about 1,122 km^3 of its total potential can be put to beneficial use, of which 690 km^3 is surface water resources. Further, about 40 per cent of the utilizable surface water resources are presently in the Ganga-Brahmaputra-Meghna system. In a majority of river basins, the present utilization is significantly high and is in the range of 50 per cent to 95 per cent of utilizable surface resources. However, in rivers such as the Narmada and Mahanadi, the percentage utilization is quite low. The corresponding values for these basins are 23 per cent and 34 per cent, respectively.

On the other hand, the ground water is another major component of the total available water resources. In the coming years the ground water utilization is likely to increase manifold for the expansion of irrigated agriculture and to achieve national targets of food production. Although the ground water is an annually replenishable resource, its availability is non-uniform in space and time.

Based on the norms given by the Ground Water Overexploitation Committee, the state governments and the Central Ground Water Board computed the gross ground water recharge as 431.42 km^3, and the net recharge (70 per cent of the gross) as 301.99 km^3.

With respect to total water requirements, as per the recent estimates made by the Ministry of Water Resources, the total withdrawal/utilization for various uses has been estimated for the present and the future years. (Table 3.1).

According to the Ministry of Water Resources, the water availability may be able to meet the requirements till the year 2050, through integrated water management plans. The issue of demand management has been given due importance in order to achieve higher levels of water use efficiencies. However, this analysis does not take into account any possible impact due to climate change. Based on the extent and level of climate change impacts, all these computations will have to be reworked.

Methods and Model Used for Simulation of Surface Runoff at River Basin Level

The present assessment aims to determine the water availability under a projected climate change scenario, initially for the HadRM2 control scenario case, without incorporating any man-made changes such as dams, diversions, etc. Second, the same framework is used to predict the impact of climate change, using the HadRM2 climate change scenario on the current availability of water resources, with the assumption that the land use will not change over time.

SWAT Model: The SWAT water balance model has been used for the river basins to carry out the hydrologic modelling of the country. The SWAT model simulates the hydrologic cycle in daily time steps. The SWAT Model routes water from individual watersheds, through the major river basin systems. SWAT is a distributed, continuous, daily hydrological model with a GIS interface for pre- and post-processing of the data and outputs.

Data used for modelling: The SWAT model requires data on terrain, land-use, soil and weather for assessment of water resources availability at the desired locations of the drainage basin. Data (1:250,000 scale) for all the river basins of the country, barring the Brahmaputra and Indus, been used. The snowbound areas of the Ganga have also not been modelled due to the lack of appropriate data.

Table 3.1: Utilizable Water, Requirement and Return Flow Based on National Average (in km^3).

Particulars	1997–1998	2010		2025		2050	
		Low Demand	High Demand	Low Demand	High Demand	Low Demand	High Demand
Utilizable Water							
Surface	690	690	690	690	690	690	690
Ground	396	396	396	396	396	396	396
Canal irrigation	90	90	90	90	90	90	90
Total	996	996	996	996	996	996	996
Total Water Requirement							
Surface	399	447	458	497	545	641	752
Ground	230	247	252	287	298	332	428
Total	629	694	710	784	843	973	1180
Return flow							
Surface	43	52	52	70	74	91	104
Ground	143	144	148	127	141	122	155
Total	186	196	200	197	215	213	259
Residual Utilizable Water							
Surface	334	295	284	263	219	140	42
Ground	219	203	202	146	149	96	33
Total	553	498	486	409	368	236	75

Source: NCIWRD, 1999.

Digital Elevation Model (DEM); is generated using contours taken from the 1:250,000 scale ADC world topographic map.

Watershed (sub basin); automatic delineated watersheds by using the DEM as input and the final outflow point on each river basin as the pour point. Figure 3.16 depicts the modelled river basins (automatically delineated using GIS), with their respective sub-basins

Daily Weather Data; generated in transient experiments by the Hadley Center for Climate Prediction, UK, at a resolution of 0.44° × 0.44° latitude by longitude grid points (red dots in Figure 3.16 for present/control (1981–2000) and future/GHG (2041–2060) climate data.

Land Cover/Land-Use Layer; classified land cover using remote sensing by the University of Maryland Global Land Cover Facility (13 categories, Source: Global Land Cover, University of Maryland Global Land cover Facility), with a resolution of 1 km grid cell size has been used.

Soil Layer; soil map adapted from FAO Digital Soil Map of the World and Derived Soil Properties (ver 3.5, FAO, 1995) with a resolution of 1: 5,000,000.

Figure 3.16: Modelled river basins along with RCM Grid Locations.

Simulated water balance at river-basin bevel: The SWAT model has been used on each of the river basins separately using daily weather generated by the HadRM2 control climate scenario (1981- 2000). The model has been used with the assumption that every river basin is a virgin area without any man-made change incorporated, which is reasonable for making a preliminary assessment. However, a general country-wide framework has been created that can be used conveniently for adding the additional information at various scales.

The model has been run using climate scenarios for the period 2041 to 2060, without changing the land-use pattern. The outputs of these two scenarios have been analyzed with respect to the possible impacts on the run-off, soil moisture and actual evapotranspiration.

The model generates detailed outputs at daily interval on flow at sub-basin outflow points, actual evapotranspiration and soil moisture status. Further sub-divisions of the total flow, such as surface and sub-surface run-off are also available. It is also possible to evaluate the recharge to the ground water on a daily basis.

Implications of Climate Change on Water Availability

Figure 3.17 shows the plot of these water balance components for the control and Climate Change Scenarios for the 12 river basins. Table 3.2 depicts the comparison of water balance components expressed as percentage of rainfall for control as well as Climate Change Scenarios. One can observe that the impacts are different in different catchments. The increase in rainfall due to climate change does not result in an increase in the surface run-off as may be generally predicted. For example, in the case of the Cauvery river basin, an

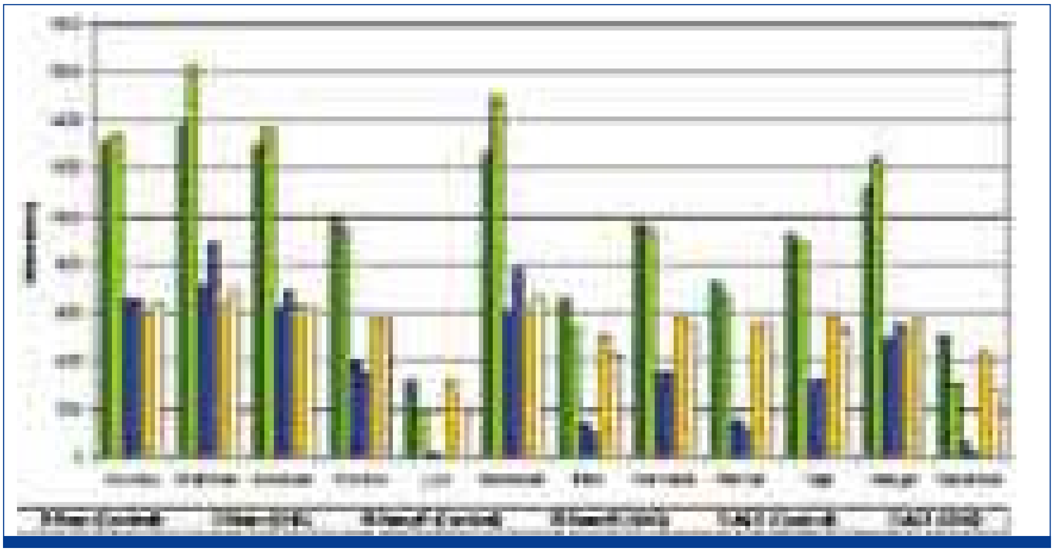


Figure 3.17: Trends in water balance for CTL and GHG climate scenarios.

Table 3.2: Comparison of change in Water Balance Components as a percentage of rainfall.

Basins	Scenario	Rainfall mm	Run-off mm	As a proportion of Rainfall (%)	Actual ET mm	As a proportion of Rainfall (%)
Cauvery	Control	1309.0	661.2	50.5	601.6	46.0
	GHG	1344.0	650.4	48.4	646.8	48.1
Brahmani	Control	1384.8	711.5	51.4	628.8	45.4
	GHG	1633.7	886.1	54.2	698.8	42.8
Godavari	Control	1292.8	622.8	48.2	624.1	48.3
	GHG	1368.6	691.5	50.5	628.3	45.9
Krishna	Control	1013.0	393.6	38.9	585.0	57.7
	GHG	954.4	346.9	36.4	575.6	60.3
Luni	Control	317.3	15.5	4.9	316.5	99.7
	GHG	195.3	6.6	3.4	207.3	106.1
Mahanadi	Control	1269.5	612.3	48.2	613.5	48.3
	GHG	1505.3	784.0	52.1	674.1	44.8
Mahi	Control	655.1	133.9	20.4	501.0	76.5
	GHG	539.3	100.0	18.5	422.7	78.4
Narmada	Control	973.5	353.4	36.3	586.8	60.3
	GHG	949.8	359.4	37.8	556.6	58.6
Pennar	Control	723.2	148.6	20.6	556.7	77.0
	GHG	676.2	110.2	16.3	551.7	81.6
Tapi	Control	928.6	311.2	33.5	587.9	63.3
	GHG	884.2	324.9	36.7	529.3	59.9
Ganga	Control	1126.9	495.4	44.0	535.0	47.5
	GHG	1249.6	554.6	44.4	587.2	47.0
Sabarmati	Control	499.4	57.0	11.4	433.1	86.7
	GHG	303.0	16.6	5.5	286.0	94.4

increase of 2.7 per cent has been projected in the rainfall, but the run-off is projected to reduce by about 2 per cent and the evapotranspiration to increase by about 2 per cent. This may be either due to increase in temperature and/or change in rainfall distribution in time. Similarly, a reduction in rainfall in the Narmada is likely to result in an increase in the run-off and a reduction in the evapotranspiration, that is again contrary to the usual myth. This increase in run-off may be due to intense rainfall as a consequence of climate change. Therefore, it is important to note here that these inferences have become possible since a daily computational time step has been used in the distributed hydrological modelling framework. This realistically simulates the complex spatial and temporal variability inherent in the natural systems.

It may be observed that even though an increase in precipitation is projected for the Mahanadi, Brahmani, Ganga, Godavari, and Cauvery basins for the Climate Change Scenario, the corresponding total run-off for all these basins has not necessarily increased (Figure 3.18). For example, the Cauvery and Ganga show a decrease in the total run-off. This may be due to an increase in evapotranspiration on account of increased temperatures or variation in the distribution of rainfall.

In the remaining basins, a decrease in precipitation is projected. The resultant total run-off for the majority of the cases, except for the Narmada and Tapi, is projected to decline. As expected, the magnitude of such variations is not uniform, since they are governed by many factors such as land use, soil characteristics and the status of soil moisture. The Sabarmati and Luni basins are likely to experience a decrease in precipitation and consequent decrease of total run-off to the tune of two-thirds of the prevailing run-off. This may lead to severe drought conditions under a future Climate Change Scenario.

The vulnerability of water resources has been assessed with respect to droughts and floods. Rainfall, run-off and actual evapotranspiration have been selected from the available model outputs, since they mainly govern these two extreme impacts due to climate change.

Droughts: Drought indices are widely used for the assessment of drought severity by indicating relative dryness or wetness affecting water sensitive regions. A soil moisture index has been developed to assess drought severity, using SWAT output that incorporates the spatial variability, to focus on agricultural drought where severity implies cumulative water deficiency.

The spatial and temporal distribution of drought conditions has been depicted in Figure 3.19. The

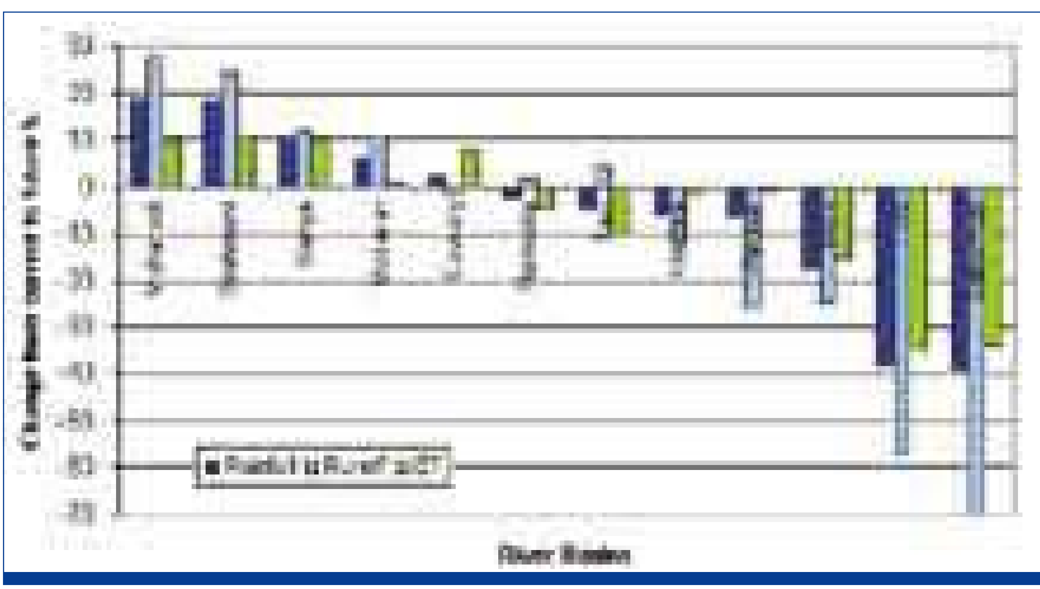


Figure 3.18: Change in water balance for CTL and GHG climate scenarios.

spatial variability of concurrent severity of drought is depicted by picking up the most severe years (in terms of number of drought weeks) in each sub-basin (depicted by graduated colour in the figure). The legend also shows the number of sub-basins where severe concurrent conditions prevailed in that year. This depiction is only with respect to the severest years for each sub-basin. It may be observed that there are three years, namely 1981, 1982 and 1983, that had on an average, one-fourth of the sub-basins covered under severe drought conditions simultaneously. The corresponding analysis on the Climate Change Scenario projects that there is only one year where the drought conditions are expected over one-third of India (61 out of 188 sub-basins). For the next two years, a relatively smaller part (less than 30 sub-basins) is likely to experience severe drought conditions simultaneously. In other words, the drought situation under the Climate change scenario may be marginally lower in terms of concurrent drought conditions.

Figure 3.19 also depicts the results of the drought analysis with respect to the intensity of drought weeks over the next 20 years in each sub-basin. The size of the green dot reveals the number of such drought weeks. A closer look at the figure suggests that there are varying trends with respect to this criterion. There are two pockets that have been identified (refer to circle 1 and circle 2 in Figure 3.19). In the one covering parts of the Sabarmati and Mahi (circle 1), the Climate Change Scenario may result in severe drought conditions in comparison to the control scenario. In areas covering parts of the Mahanadi and Brahmani (circle 2), the drought conditions are likely to be less severe under the Climate Change Scenario.

Floods: A Vulnerability assessment with respect to floods has been carried out using the daily outflow discharge from each sub-basin of the SWAT output. These discharges have been analyzed with respect to the peaks only in the absence of other relevant information, such as gauge discharge data and gauge locations. The maximum daily peak discharge has been identified for each year and for each sub-basin. A simple analysis has been performed to identify those basins where flooding conditions may deteriorate under the Climate Change Scenario.

Figure 3.20 shows the spatial distribution of annual maximum daily peak for the 19th year for the control scenario (as a sample year) along with the 20-year bar charts for control and Climate Change Scenarios, for each of the sub-basins of the Mahanadi. The figure also depicts two maximum annual peaks for the Climate Change Scenario for the furthest downstream

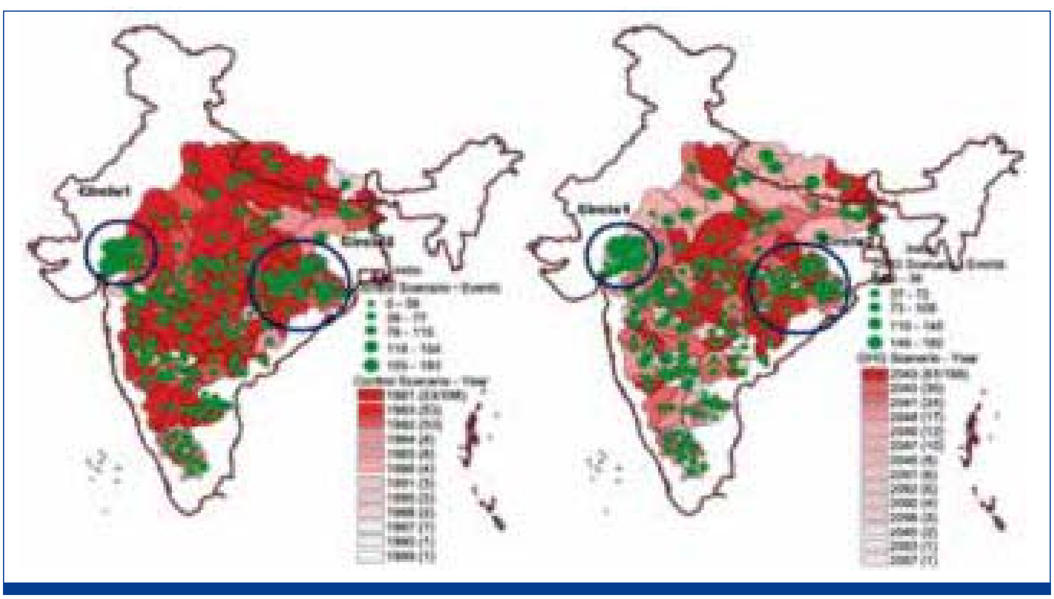


Figure 3.19: Spatial and temporal distribution of drought conditions.

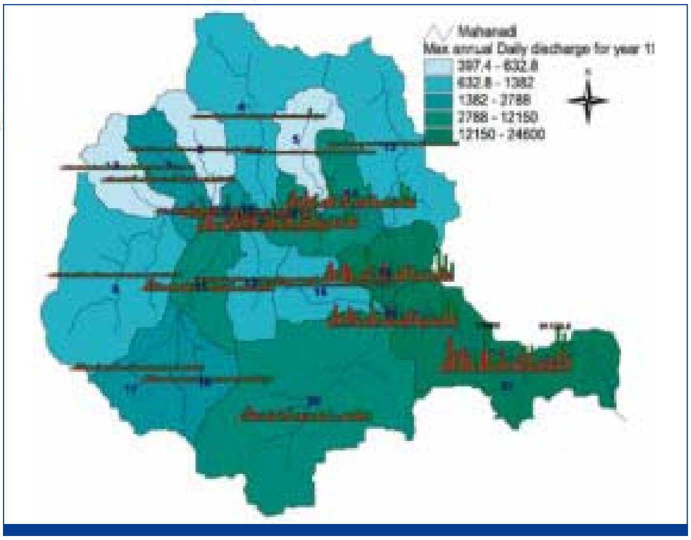


Figure 3.20: Annual maximum daily peak discharges for sub-basins of the Mahanadi.

sub-basin (21). It may be observed that these peaks are more than double the magnitude of the maximum peak of the control scenario.

Overall impact and vulnerability: The preliminary assessment has revealed that under the GHG scenario, the severity of droughts and intensity of floods in various parts of India is projected to increase. Further, there is a general reduction in the quantity of the available run-off under the GHG scenario (Figure 3.21). Luni, the west flowing river of Kutchh and Saurastra occupying about one-fourths of the area of Gujarat and 60 per cent of the area of Rajasthan are likely to experience acute physical water scarce conditions. The river basins of Mahi, Pennar, Sabarmati and Tapi are likely to experience constant water scarcities and shortage. The river basins of Cauvery, Ganga, Narmada and Krishna are likely to experience seasonal or regular water-stressed conditions. The river basins of the Godavari, Brahmani and Mahanadi are projected to experience water shortages only in a few locations.

Limitations of the Study: The water availability derived for the HadRM2 control scenario case in space and time does not incorporate any human interventions such as dams and diversions. The same framework has then been used to predict the impact of climate change (using the HadRM2 GHG scenario), with the assumption that the land use will not change over time. The 'hot spots' have been identified only with respect to the natural boundaries in the form of sub-basins of the river systems. Before the adaptation issues are addressed, it is imperative to develop a better understanding of these hot spots by qualifying these geographic areas with respect to their populations and ecosystems. Box 3.5 lists some

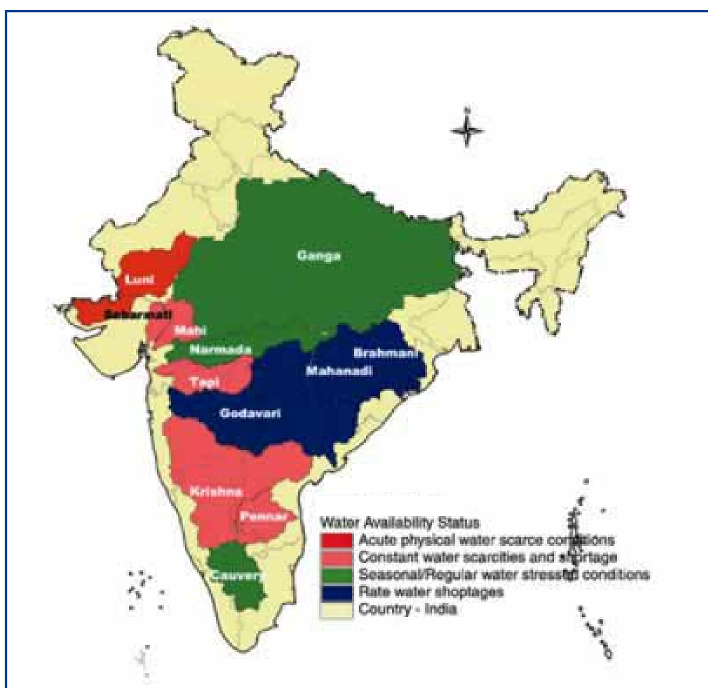


Figure 3.21: Broad variation in vulnerability of different regions to projected climate change.

of the likely effects of climate change on ground water resources and on the glaciers in India.

Practices for Vulnerability Reduction

Government Policies and Programmes

The Government of India, as well as several state governments have launched various programmes to conserve and develop water resources for agricultural and domestic sectors. These programmes, which aim at conservation and sustainable use of water resources, also reduce vulnerability to water stress. The centrally-sponsored scheme for soil conservation for the enhancement of productivity of degraded areas in the catchments of River Valley Projects and Flood Prone Rivers (RVP and FPR) is being implemented on a watershed basis in 45 selected catchments throughout the country. Other schemes include the Drought Prone Areas Programme (DPAP), Desert Development Programme (DDP), National Watershed Development Programme for Rainfed Areas (NWDPRA), Soil, Water and Tree Conservation (Operation Soil Watch), Operational research projects on Integrated Watershed Management, and the Jawahar Rojgar Yojana (JRY). All these programmes had definite objectives: improvement of productivity of catchment areas, optimum use of soil, land, water and their conservation, employment generation, etc.

Watershed Development Programme: This programme has been in operation for nearly 40 years. It has emphasized the importance of soil and water conservation and people's participation through Watershed Associations in planning and management. Overall national objectives of reducing the adverse impact of droughts, improving/stabilizing the production of important rainfed crops like pulses and oilseeds, and controlling siltation of reservoirs, have not been achieved to a satisfactory level. However, the impact of some of the watershed projects in reducing siltation, expansion of cropped area, increase in cropping intensity and grain/biomass yields has been very pronounced and visible on the ground. The

Box 3.5: Ground Water

It is estimated that ground water levels have already declined in about 0.34 million km^2. Although efforts are being made for improved water management practices, like water conservation, artificial recharge and watershed management, utilization of non-conventional energy and integrated water development, the projected water demand of a minimum 980 BCM during 2050 will require intensive development of ground water resources, exploiting both dynamic and in-storage potential. It is apparent that the projected climate change leading to global warming, sea-level rise and melting of glaciers will disturb the water balance in different parts of India and quality of ground water along the coastal track. Possible effects of climate change on ground water are:

- changes in precipitation and evapotranspiration may influence ground water recharge;
- rising sea levels may lead to increased saline intrusion of coastal and island aquifers;
- increased rainfall intensity may lead to higher run-off and less recharge; and
- increased flood events may affect groundwater quality in alluvial aquifers.

Climate Change Impact Assessment on Uttaranchal Himalayan Glaciers

- The glaciers and the snowfields in the Himalayas are on the decline.
- The rate of retreat of the snout of Gangotri glacier demonstrated a sharp rise in the first half of the 20th century. This trend continued up to around the 1970s, and subsequently there has been a gradual decline in its rate of retreat.
- The diminishing rate of retreat of the snout of the Gangotri glacier could be a consequence of the diminishing rate of rise in the temperatures.
- Although the warming processes continue unabated, the rate of rise in temperatures in the Gangotri glacier area has nevertheless demonstrated a marked gradual decline since the last quarter of the past century.

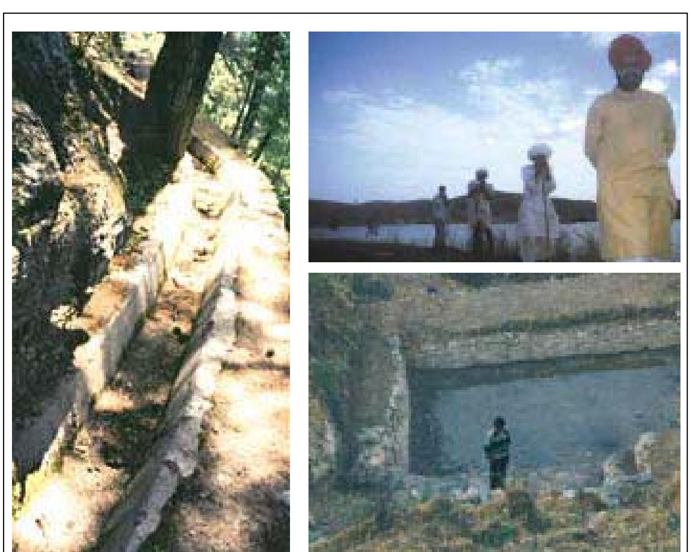
watershed development programme has emphasized soil and water conservation efforts/methods, but not on productivity-linked best agronomic practices.

Command Area Development Programme (CAD): This programme has a positive impact on irrigation water utilization, irrigation intensity, agricultural productivity, and soil and water environment. It has been felt that the main emphasis of CAD has so far been on physical works, such as construction of field channels and on-farm development work.

Crop Diversification: Crop diversification methods such as crop rotation, mixed cropping and double cropping, reduce the vulnerability of crop yields. Crop diversification has also been found to result in reduced erosion, improved soil fertility, improved crop yield, reduced risk of crop failure and enhanced water savings.

Expansion of Irrigation and Irrigation Water Management: Irrigation reduces the vulnerability of crop yields to the vagaries of rainfall. India has implemented a large programme to expand irrigation from diverse sources. However, about 60 per cent of the net sown area is still under rainfed cropping. Further, the water resources need to be managed efficiently so that wastage is minimized. Management issues should include linkages with the farmers, command area development, water conservation techniques, participatory irrigation management and institutional reforms. All reforms must be backed by research and diagnostic analysis for optimal results. The efficiency of existing systems needs to be enhanced such that the savings in water is utilized to increase irrigation intensity. Irrigation consumes nearly 83 per cent of water being used at present. It is estimated that even in the year 2050, it will continue to consume about 79 per cent of the total consumption. Even a nominal saving of 10 per cent in irrigation water can result in an increase in the availability of water for domestic and industrial uses by about 40 per cent in the long term. Such increase may also be used to offset the impacts of climate change in areas where reduction in water availability is projected.

Flood Control and Flood Management: Flooding is a major problem in the Himalayan rivers. About 40 Mha, which is close to one-eighth of the geographical area of the country, is vulnerable to floods. Flood protection works in the form of flood embankments and reservoirs have not proved very useful. It has been felt that it may not be possible to provide complete protection against floods. It is recommended that India should lay more emphasis thus on the efficient management of flood plains, flood proofing, including disaster preparedness and response planning, flood forecasting and warning, and many other non-structural measures.



Some of the traditional water conservation techniques.

The National Flood Commission *(Rashtriya Barh Ayog)* was set up in 1976 by the Government of India to review and evaluate the flood protection measures undertaken since 1954, and to evolve a comprehensive approach to the problem of floods. .

In 1996, Government of India set up a Task Force to review the impact of recommendations of the *Rashtriya Barh Ayog* and analyze the strategies evolved so far for mitigating flood problems and suggest both short-term and long-term measures.

Farmers Practices

Traditionally, farmers observe a number of practices to adapt to climate variability, for example, inter-cropping, mixed cropping, agro-forestry and animal husbandry (sheep rearing).

The vulnerability to increased water stress can be reduced through the participation of farmers in improved management of irrigation, adopting local rainwater harvesting systems, watershed development, low-cost drip irrigation, resource conserving technologies, such as zero tillage, bed planting, and adoption of multiple crops or crop diversification, etc.

Adaptation Strategies

The projected impact of climate change is likely to exacerbate the water stress and shortages in some regions and also increased flooding in others. Thus, there is a need to develop and implement adaptation measures. These strategies may range from change in land use and cropping patterns to water conservation, flood warning systems, crop insurance, etc.

The strategy for coping with the climate change impacts on national water resources will be similar to the current strategies for coping with the ever-increasing demands and shortages. A prerequisite to adaptation is the application of an Integrated Water Resources Management strategy at different levels of usage from individual households to local communities, and watersheds to catchments. The current strategies to adapt to the two extreme events, namely floods and droughts, will hold good even to the projected impacts of climate change. The present structural or non-structural measures of flood protection will continue to be valid. Structural measures include the construction of dams for flood control by flattening flood peaks, and the construction of levies and dikes to safeguard the installations from flooding. Non-structural measures may include flood plain zoning, flood forecasting systems, flood insurance and flood preparedness.

Traditional as well as technological approaches are used to cope with the risk of drought. Technological management of drought uses medium (seasonal) to long-term (annual to decadal) forecasts that are formulated using appropriate models. This information is then translated into early warning, and subsequently appropriate drought protection measures are taken. Some of the possible supply side measures may include augmentation of the supply of water by sustainable extraction and use of surface water and groundwater in the local area, and long distance transfers of water from surface and groundwater sources.

Box 3.6: Ground water harvesting for reviving traditional step wells

Many cities in India have traditional water harvesting and conservation structures, called *Baolis* or step wells. These can be revived and effectively used to recharge ground water. Water harvesting in neighbouring areas recharges these wells naturally and can supply water to the neighbourhood during the lean period. The national capital Delhi is dotted with *Baolis* constructed by the Mughals in India. Water is a scarce commodity in Delhi specially during the summers. The Indian National Trust for Arts and Culture (INTACH) has taken an initiative to revive these step wells in Delhi.

Improving the water availability through the year, revival of diverse and community-based irrigation systems, soil and water conservation, equitable water distribution, traditional water conservation practices, and groundwater recharge, are examples of adaptation strategies (see Box 3.6). The Government of India is also envisaging the linking of rivers to mitigate droughts, as well as floods in the long term.

Common Framework for Adaptation Strategy: This implies that a common framework is essential to be created at the country level that should be used towards implementing the integrated watershed management strategy starting from the *Gram Panchayat* (village council) to the river-basin level in a unified manner. Integrated watershed management does not merely imply the amalgamation of different activities to be undertaken within a hydrological unit. It also requires the collation of relevant information, so as to evaluate the cause and effect of all the proposed actions. This framework will need regular maintenance and updating to fully reflect the most accurate ground truth data. Local planning and management strategies have to be evolved and validated through the proposed framework, so as to generate and evaluate various options suitable for local conditions.

One of the strategies may be to opt for artificial restoration of the hydrological system by the enhancement of water storage and infiltration of rainfall in urban areas and in river basins in order to maintain the original water balance. This will be useful for ecological and water resources restoration and implementation of nature-oriented river improvement works.

There is no single 'best' coping strategy. The best choice is a function of many factors pertaining to economic efficiency, risk reduction, robustness, resilience, reliability, etc. The emerging technologies for short-term weather forecast for real-time water management and operations have a large potential to enhance the coping capabilities to climate variability and change. Such advancements will greatly improve the irrigation water management efficiency. Biotechnology holds promise that may help in increasing crop yields while reducing the water requirement and developing crops that are less dependent on water. This has a large potential and relevance in water-stressed areas, as well as areas with low water quality.

In general, the financial, technological and institutional barriers usually hamper the implementation of adaptation measures to climate variability and change. Although, the current water policy of India aims at integrated water resources development and management to tackle water stress, its implementation is constrained by financial and technological limitations.

The projected impacts of climate change are likely to exacerbate the water stress and shortages in some regions and increase the frequency and intensity of floods and droughts. However, there are uncertainties in the climate change projections and impact assessment on water resources at the regional level. Thus, there is a need to improve the reliability of climate change projections at the regional level and its integration in the modelling to project impacts on water resources at the regional level, if not the local or watershed level.

CLIMATE CHANGE IMPACTS ON AGRICULTURE

Indian Agriculture scenario

Food grain production in India has increased spectacularly due to the Green Revolution from 50 Mt in 1951 to 212 Mt in 2002, and the mean cereal productivity has increased from 500 kg ha^{-1} to almost 1800 kg ha^{-1}. These increases were largely the result of area expansion, large-scale cultivation of new high-yielding semi-dwarf varieties since the early 1960s, and the increased application of irrigation, fertilizers and biocides, supported by progressive government policies (Figure 3.22). Today, we have 190 Mha gross sown area (142 Mha net sown area), and 40 per cent of this is irrigated. There have been similar revolutions in the production of milk, fish, eggs, sugar, and a few

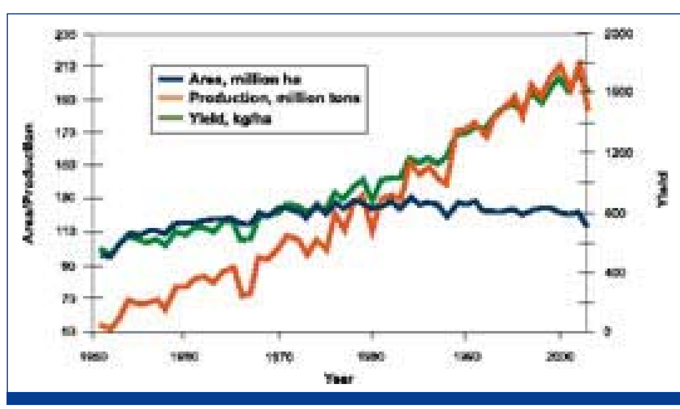


Figure 3.22: Change with time in area, production and yield of food grains.

Marginal farmers dependent on rain are at risk due to climate change.

other crops. India is now the largest producer of milk, fruits, cashew nuts, coconuts and tea in the world, the second largest producer of wheat, vegetables, sugar and fish, and the third largest producer of rice. As a consequence, the per capita availability of food grains has risen in the country from 350 gm in 1951, to about 500 gm per day at present, from less than 125 gm of milk to 210 gm per day, and from 5 to 30 eggs per annum despite the increase in population from 350 million to more than one billion. This growth in agricultural production has also led to considerable surplus food stocks with the government. The droughts of 1987, 1999-2000, and of 2002-2003 could generally be managed and did not lead to severe problems of food security because of these buffer stocks.

Table 3.3. Food demand assuming a 5 per cent GDP growth at constant prices.

Items	Production (Mt)	Demand (Mt)	
	1999-2000	2010	2020
Rice	85.4	103.6	122.1
Wheat	71.0	85.8	102.8
Coarse grains	29.9	34.9	40.9
Total cereals	184.7	224.3	265.8
Pulses	16.1	21.4	27.8
Fruits	41.1	56.3	77.0
Vegetables	84.5	112.7	149.7
Milk	75.3	103.7	142.7
Meat and eggs	3.7	5.4	7.8

Despite this progress, food production in India, on an aggregated scale, is still considerably dependent on the rainfall quantity and its distribution. The summer monsoon (June through September) contributes 78 per cent of India's annual rainfall and is a major water resource. It is important to recognize that the Green Revolution was largely confined to the irrigated areas. In the past 50 years, there have been around 15 major droughts, due to which the productivity of rainfed crops in those years was affected. Limited options of other income and widespread poverty continue to threaten the livelihood security of millions of small and marginal farmers in this region.

The food security of India may be at risk once again in the future, due to the continued population growth. By 2050, India's population is projected to grow to 1.6 billion. This rapid and continuing increase in the population implies a greater demand for food. The demand for rice and wheat, the predominant staple foods, is expected to increase to 122 and 103 Mt, respectively, by 2020, assuming medium income growth (Table 3.3). The demand for pulses, fruits, vegetables, milk, meat, eggs and marine products is also expected to increase very sharply. This additional food will have to be produced from the same or possibly shrinking land resource base, because there is no additional land available for cultivation. It is estimated that the average yields of rice, wheat, coarse grains, and pulses need to increase by 56, 62, 36 and 116 per cent, respectively, by 2020.

Although there is pressure to increase production in order to meet higher demands, there has lately been a significant slow-down of the growth rate in cultivated area, production and yield. The annual rate of growth in food production and yield peaked during the early years of the Green Revolution, but since the 1980s, it has declined.

The perceived gradual increase in environmental degradation, the early signs of which are becoming visible in areas that benefitted largely from the Green Revolution technologies, is further compounding the problem. There is now great concern about declining soil fertility, change in water table depth, rising salinity, resistance of harmful organisms to many pesticides, and degradation of irrigation water quality as, for example, in north-western India. Nutrient removal by crops over time has exceeded its application and consequently, farmers now have to apply more fertilizers to realize the same yield as achieved 20-30 years ago. The introduction of canal irrigation in Haryana has resulted in almost 0.5 Mha being affected by soil salinity. The rapid increase in the number of tube-wells during the last three decades has resulted in over-exploitation of groundwater in many blocks, leading to declining water tables. In some canal irrigated districts, on the other hand, the water table has risen, resulting in increased problems of salinity. Several pathogens and insect pests have also shown a tendency to increase under the intensive farming systems such as rice-wheat system.

FACE set-up at the Indian Agricultural Research Institute to study the impact of increased CO_2 on crops.

In the 21st century, one of the great challenges for Indian agriculture will be, therefore, to ensure that food production is coupled with both poverty reduction and environmental preservation. The road-map of sustainable agricultural development may also have to consider two additional important global drivers of change in agriculture in the coming decades -globalization and climate change. The on-going globalization process and economic reforms associated with the World Trade Organization (WTO) is forcing India to make structural adjustments in the agricultural sector to increase its competitiveness and efficiency.

VULNERABILITY OF AGRICULTURE

Methods and models

All available methods have been utilized by the Indian scientific community for assessing the possible impact of climatic variability and climatic change on agriculture. Historical data analyses by various statistical tools and the analogue approach have traditionally been used to assess the impact of climatic variability. Since environmental control, particularly of CO_2, is very difficult and expensive, there have been only a few studies globally in estimating its direct impact on crop plants. Controlled environment facilities, such as open top chambers, Phytotron, and greenhouses, are now increasingly being used to understand the impact of temperature, humidity and CO_2 on crop growth and productivity. Greater efforts are now also being made to establish Free Air CO_2 Enrichment (FACE) facilities, where CO_2 is artificially increased in field conditions to quantify its possible impacts. One such facility has recently been set up at the Indian Agricultural Research Institute, New Delhi, to study the effect of increased CO_2 on crop photosynthesis and yield (see photograph above).

The interactive effects of CO_2, rainfall and temperature can be best studied through the use of crop growth simulation models. These models simulate the effect of daily changes on weather (including those caused by climatic change), for any location on growth and yield of a crop through the understanding of crop physiological and soil processes. Several crop models have also been used in India for impact assessment of climatic variability and climate change. Models of various crops included in the Decision Support System for Agro-technology Transfer (DSSAT) shell have been the most popular. For rice, the ORYZA series of models have been effectively used. Indian models, such as the Wheat Grown Simulator (WTGROWS) for wheat, have been the basis of a large number of studies. Greater use of such crop models for impact assessment of climate change is, however, limited, due to the lack of a user-friendly framework that requires limited inputs and considers yield reduction due to pests and diseases in the tropics. InfoCrop is one such indigenous decision support system, based on crop models that have been developed recently at the Indian Agricultural Research Institute to meet the stakeholders' need for information on vulnerability of agriculture to climate change and for optimizing crop management. The InfoCrop modelling framework requires limited inputs and also includes databases of typical Indian soils, weather and genotypes. The current version of the model deals with chickpea, cotton, groundnut, maize, mustard, pearl millet, pigeonpea, potato, rice, sorghum, soybean, sugarcane, and wheat.

Impact assessment

The net availability of food at any given time depends on a number of local, regional, national and international factors. Climate change associated variables such as CO_2 and temperature can influence food availability through their direct effect on growth processes and yield of crops. In addition, it may also impact crop production through indirect effects caused by, for example, change in rainfall induced irrigation availability, soil organic matter transformations, soil erosion, changes in pest profiles, and decline in arable areas due to the submergence of coastal lands. Equally important determinants of food supply are socio-economic environment including government policies, capital availability, prices and returns, infrastructure, land reforms, and intra- and international trade that might be affected by climatic change.

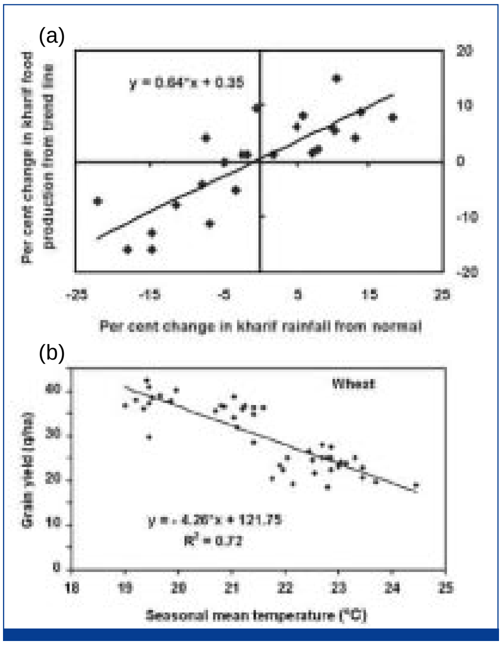


Figure 3.23. a) Relation of monsoon season food production with seasonal rainfall; and b) of regional wheat yields with seasonal temperature.

Direct effects on crop growth and yield

Several studies are available that relate crop yields/ production directly with one or more variables of weather. Many of these results are confounded by the differences in technological growth over space and time. Nevertheless, many of these studies have shown that the annual food production in the monsoon season (*kharif*) of the country has a positive relationship with the seasonal rainfall, even after considering the deviations from the technology trend line (Figure 3.23a). In the post-monsoon season, the rainfall is scanty, and crops such as wheat, that dominate food production are largely irrigated. Hence, such crops do not show any relation with the seasonal rainfall. However, the regional wheat yields do show a considerable relation with temperature, as shown in Figure 3.23b.

Such empirical relations of crop yield with weather are not universal, relate only to one element of weather, are data specific, and do not provide any insight into mechanisms of the associations. Dynamic simulation models are able to overcome these limitations. In recent years, such crop models have been used in India to assess the impact of climate change on crop production in different regions. In these studies, the sensitivity of crops to simultaneous, as well as independent changes of different magnitude in temperature and carbon dioxide, has been studied. The advantage of such an analysis is that the direct effects of all possible scenarios of climate change including those of the IPCC, even up to the year 2070, can be considered.

Most of the simulation studies have shown a decrease in the duration and yield of crops as temperature increased in different parts of India (Aggarwal et al., 2001). These reductions were, however, generally offset by the increase in CO_2; the magnitude of this response varied with crop, region and climate change scenario. The results of such studies for rice and wheat are illustrated in Figure 3.24. Yields of both crops decreased as temperature increased; a 2°C increase resulted in 15-17 per cent decrease in the grain yield of both crops, but beyond that the decrease was very high in wheat. These decreases were compensated by

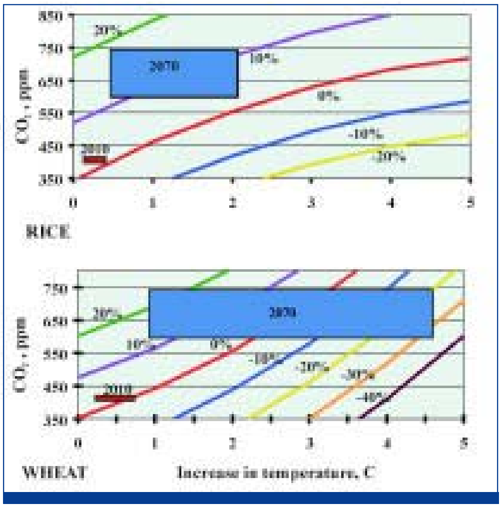


Figure 3.24. Simulated response of irrigated rice and wheat in northern India to changes in temperature and CO_2. The lines refer to the equal change in grain yield (percentage change, labelled values) at different values of CO_2 and increase in temperature. The large, shaded box refers to the total uncertainty in impact assessment due to uncertainties in the IPCC scenario of 2070. The small, hatched box refers to the total uncertainty due to uncertainties in the scenario of 2010.

an increase in CO_2, due to the latter's fertilizing effect on crop growth. Atmospheric CO_2 concentration has to rise to 450 ppm to nullify the negative effect of a 1°C increase in temperature, and to 550 ppm to nullify the 2°C increase in temperature.

The sensitivity analysis of yield to temperature and CO_2 as presented in Figure 3.24 can assist in assessing the direct impact of different climate change scenarios, and their uncertainties on different crops. Based on various IPCC scenarios, two specific scenarios of climate change-optimistic and pessimistic-for different years, from 2010, were used for further evaluation. The highest increase in temperature and lowest increase in CO_2 are detrimental to crop growth and, hence, this is labelled as a pessimistic scenario. On the other hand, large increase in CO_2 and a small change in temperature promote growth and, hence, is labelled as an optimistic scenario. The uncertainty in global warming and its impact during the period 2010 to 2070 are assumed to be in between these two scenarios. Superimposing these scenarios on the

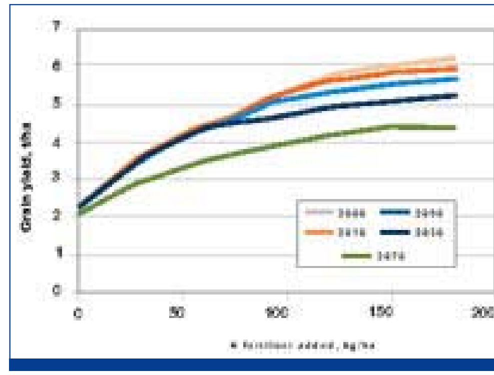


Figure 3.25. Simulated response of irrigated wheat in north India to improved management (N fertilizer) in global warming scenarios of future years.

isolines in Figure 3.25 can guide us on the magnitude of the potential impact of change on crop productivity. Both rice and wheat showed a small positive effect with an increase in yield between 1 per cent and 5 per cent (area within the box). The effect remained positive (5-20 per cent) in the case of rice, even by 2070, due to the effect of a large increase in CO_2 compared to a relatively small reduction in *kharif*[2] temperature. By comparison, the effect on wheat could be positive (up to 25 per cent) or negative (up to 30 per cent), depending upon the magnitude of change in CO_2 and temperature. Since, there is greater probability of increase in temperature in *rabi*[3], it is likely that the productivity of wheat and other *rabi* crops would be significantly reduced. Therefore, if CO_2 stabilizes early and the temperature continues to rise for a longer time, Indian agriculture could suffer significantly in the long term.

This impact assessment analyses was extended for various cereal crops in different regions for the climate change scenarios of 2010. The results showed that irrigated rice yields register a small gain irrespective of the scenario at all places in India (Table 3.4). Wheat yields in central India are likely to suffer by up to 2 per cent in the pessimistic scenario but there is also a

[2] *Kharif* crops are sown in May-June and harvested in September-October. The important *Kharif* crops are cotton, rice, sugarcane, maize, jowar and bajra.

[3] *Rabi* crops are sown in October-November and harvested in February-March. The important *Rabi* crops are wheat, grams, barley, rapeseed and mustard.

Table 3.4: Simulated impact of climate change scenario of 2010 on yields (percentage change) of major cereals.

Crop and region	Impact of climate change on yield, %	
	Pessimistic scenario	Optimistic scenario
Rice		
East	2.3	5.4
South	1. 3	3.8
North	3.0	7.0
Wheat		
North	1.5	6.5
East	-0.3	7.7
Central	-2.0	6.5
Sorghum		
North	0.0	0.5
South	1.0	3.4
East	1.8	2.5
West	-0.8	0.5

Note: Pessimistic scenario reflects low increase in CO_2 and a high increase in temperature, whereas the optimistic scenario consists of a significant increase in CO_2 and a negligible increase in temperature.

possibility that these might improve by 6 per cent if the global change is optimistic. Sorghum, being a C4 plant, does not show any significant response to increase in CO_2 and hence the different scenarios do not affect its yield. However, if the temperature increases are higher, western India may experience some negative effect on productivity due to reduced crop durations. This effect can be mitigated easily by using varieties that are of relatively longer duration.

Concerns have been expressed lately that the rice-wheat system in north-western India is already showing signs of stagnation/decline in its productivity. A crop simulation study with weather as the only varying factor with the year also showed a similar trend, indicating that crop-weather interactions also have a role to play in explaining the trends. A closer examination of the weather data, the main drivers in the simulations, indeed indicated that a significant part of the yield decline/stagnation trend in rice and wheat could be ascribed to rising temperatures during the crop season. These changes are not statistically significant but do indicate a warming trend and their possible effects on crop production.

A large number of resource-poor farmers in India are not able to apply desired levels of fertilizers, irrigation and pest control. Simulation studies done at different levels at N management indicate that the crop response could vary depending upon the N management and the climate change scenario (Figure 3.25). At zero kg N/ha, the yields in different scenarios of climate change were similar. This was the case even at 75 kg N/ha, except in the scenario of 2070, when the temperatures had increased to 4.5°C. The impact of warming scenarios becomes apparent at higher levels of fertilizer application from 2030 onwards. This indicates that in the agro-ecosystems where inputs used remains low, as in today's rainfed systems, the direct impact of climatic change would be small. It is also expected that the response of crops to the added fertilizer would be lower, as climate becomes warmer. In future, therefore, much higher levels of fertilizer may need to be applied to meet the increasing demand for food.

Impact assessment of climate change has also been studied for regional wheat production using crop models, Geographic Information Systems (GIS), remote sensing and regional databases. The actual dates of planting, varieties, and the fertilizer use obtained from the government survey reports, standard soil data, the irrigated regions demarcation, and weather data are input in Info-Crop to estimate crop yields. Together with remotely sensed area estimates, these are then translated into production figures in different states. This methodology has been validated with wheat production data at the state as well as national level, for three consecutive years. The results indicated, similar to the individual field level results, that we should not expect any significant effect on wheat production due to climate change up to 2010 (Figure 3.26). It was only when we consider scenarios of climate change beyond 2020, without any new technological interventions and adaptation mechanisms, a reduction in wheat production is noticed.

The increased climatic variability may affect our rainfed crops, such as pulses, significantly. A recent study analyzed the response of soybean at a few places in Madhya Pradesh, using a crop simulation model.

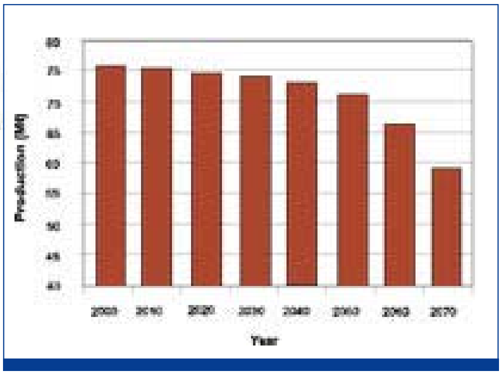


Figure 3.26. Possible impact of climate change on wheat production in India.

It showed that an increase of 3°C in temperature nullified the positive effect of doubled CO_2 on yield. The study has also shown that the magnitude of the beneficial effect of elevated CO_2 was significantly reduced under water stress conditions. Similarly, in rainfed groundnut, the simulation results have indicated that yields would increase under doubled CO_2, and temperature increase up to 3°C if the rainfall did not decline. Reduction of rainfall by 10 per cent reduced the yield by 12.4 per cent. The adaptation options should aim at increased water productivity under rainfed conditions.

There is a great probability of significant effects of increased climatic variability on short season crops such as vegetables, if changes occur during critical periods in growth. Such crops will have limited time to adapt to adverse environments. The production of fruits may be significantly affected if the changes in climate happen to coincide with the critical periods.

In the hills, the low temperature and shorter growing period limit the productivity of crops. These restrictions become conspicuous with increase in altitude. Global warming is likely to prolong the growing season and this could result in potentially higher crop yields, provided water remains available. However, the positive perspectives for total biomass production may not always ensure higher economic yields, since many temperate crops also need a minimum chilling period to stimulate better flowering. Global warming will push the snow line higher and dense vegetation will shift upwards. This shift will be selective and species specific due to the differential response of plants to changing environmental conditions. Species which are adapted to wider environmental gradients would spread faster and dominate the ecosystem, while those with narrow environmental adaptation would become marginalized. This may affect biodiversity. Corrective steps must be taken to avoid the elimination of plant species due to weather change.

The quality of food is significantly affected by temperature in most crops. An increase in temperature may have significant effect on the quality of cotton, fruits, vegetables, tea, coffee, aromatic and medicinal plants. The nutritional quality of cereals and pulses may also be moderately affected which, in turn, will have consequences for our nutritional security. Research has indeed shown that the decline in grain protein content in cereals could partly be related to increasing CO_2 concentrations.

The global environmental changes may aggravate the current problems of sustainability and profitability of agriculture in many regions of the country. These changes may alter the interactions between biophysical and socio-economic factors and the ways in which these are mediated by the institutions. Some preliminary studies have linked the biophysical response of crops, costs-benefits and the expected response of farmers to understand the socio-economic impact of global change. These indicate that the loss in farm-level net revenue may range between 9 per cent and 25 per cent for a temperature rise of 2-3.5°C.

Indirect effects on crops

Agricultural production may be much more affected by several other factors than the direct effects considered in the above analysis. Changes in pest scenario, soil moisture storage, irrigation water availability, mineralization of nutrients, and socio-economic changes can have larger effects on agricultural production. Some of these are considered below.

Crop-pest interactions

It is estimated that insect pests, pathogens and weeds result in almost 30 per cent loss in crop production at present. Avoidance of such loss constitutes one of the main sources of sustainability in crop production. The change in climate may bring about changes in population dynamics, growth and distribution of insects and pests. Besides having a significant direct influence on the pest population build up, the weather also affects the pest population indirectly through its effects on other factors like food availability, shelter and natural enemies.

Aphid is a major pest of wheat and its occurrence is highly influenced by weather conditions. Cloudy weather with sufficient relative humidity favours the occurrence of aphids in the field. Under most favourable conditions, a population density of a 1000 million per hectare wheat field has been reported. The weather changes may lead to aphid occurrence at a very juvenile and more susceptible stage of crop, leading to tremendous loss. In nature, aphids are checked by *Coccinella septumpunctata* and in case the weather limits their growth, the production losses could get further magnified. With small changes, the virulence of different pests changes. For example, at 16°C, the length of the latent period is small for yellow rust. Once the temperature goes beyond 18°C, this latent period increases but that of yellow and stem rusts decreases. The appearance of black rust in northern India in the 1960s and 1970s was related to the temperature-dependent movement of spores from southern to northern India (Figure 3.27). Thus, any small change in temperature can result in changed virulence as well as the appearance of new pests in a region.

Several pathogens such as the *Phytophtora* and *Puccinia* group produce an abundance of propagules from the infected lesion or spot. They also invariably possess very short incubation cycles or life-cycle periods. Such pathogens and pests are highly sensitive to even minor changes in temperature, humidity and sunlight. Any change in the weather conditions that further reduce the incubation period will result in the completion of more cycles, greater terminal severity and in more severe yield losses. Changes even to the extent of 1°C in maximum or minimum temperature will make a great deal of difference between moderate and severe terminal disease development. The swarms of locust produced in the Middle East usually fly eastward into Pakistan and India during the summer and they lay eggs during the monsoon. Changes in rainfall, temperature and wind speed pattern may influence the migratory behaviour of the locust.

Most crops have C3 photosynthesis (responsive to CO_2), while many weeds are C4 plants (non-responsive to CO_2). The climate change characterized by higher CO_2 concentration will

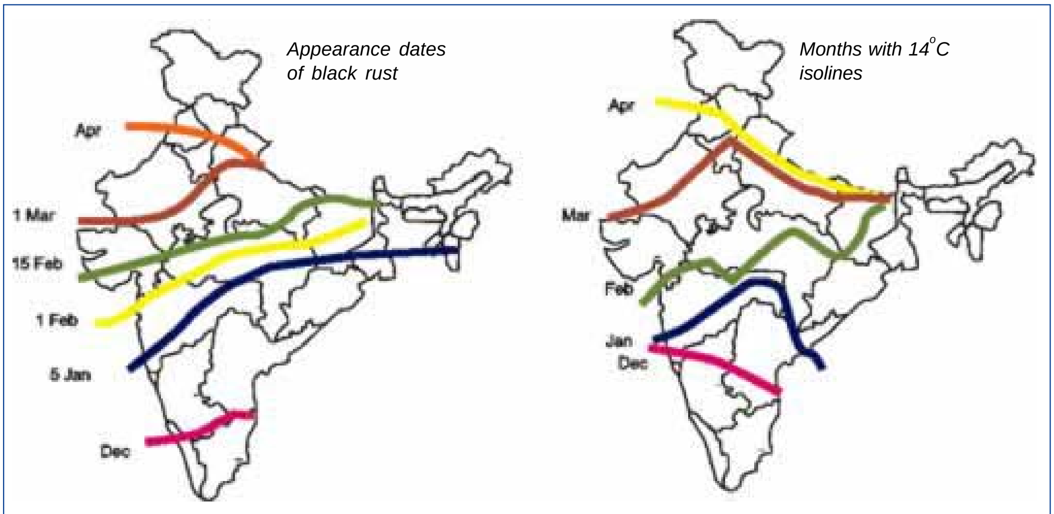


Figure 3.27. Appearance dates of black rust in 1972-73 and its relation to changes in temperatures in different regions of India. Rusts move from south to north of India, as the temperatures become suitable for them in northern regions

favour crop growth over weeds, although temperature increase may further accelerate crop-weed competition depending upon the threshold temperatures in different locations.

Water availability

The creation of irrigation potential has been a major key to India's agricultural development, production stability and food security. Apart from the monsoon rains, India has depended on the Himalayan rivers for centuries for its water resource development. Temperature increase associated with global warming will increase the rate of snow melting and consequently snow cover will decrease. In the short term, this may increase water flow in many rivers that, in turn, may lead to increased frequency of floods, especially in those systems where water carrying capacity has decreased due to sedimentation. In the long run, however, a receding snow line would result in reduced water flow in rivers. These issues have been discussed in detail elsewhere in this Communication.

Under the climate change scenario, the onset of the summer monsoon over India is projected to be delayed and often uncertain. This will have a direct effect not only on the rainfed crops, but water storage will also be affected, placing stress on the irrigation water. Since the availability of water for agriculture would have to face tremendous competition for other uses of water, agriculture would come under greater strain in future.

Soil processes

Practically all soil processes important for agriculture are directly affected in one way or the other by climate. Changes in precipitation patterns and amount, and temperature can influence soil water content, run-off and erosion, workability, temperature, salinization, biodiversity, and organic carbon and nitrogen content. Changes in soil water induced by global climate change may affect all soil processes and ultimately, crop growth. An increase in temperature would also lead to increased evapotranspiration, which may result in the lowering of the groundwater table at some places. Increased temperature coupled with reduced rainfall may lead to upward water movement, leading to accumulation of salts in upper soil layers. Similarly, a rise in sea level associated with increased temperature may lead to salt-water ingression in the coastal lands, making them unsuitable for conventional agriculture.

Organic matter content, which is already quite low in most parts of India, will continue to remain low but climatic change through temperature and precipitation mediated processes may affect its quality. An increase of $1^{o}C$ in the soil temperature may lead to higher mineralization but N availability for crop growth may still decrease due to increased gaseous losses. Biological nitrogen fixation under elevated CO_2 may show an increase, provided other nutrients are not strongly limiting.

The change in rainfall amount and frequency, and wind may alter the severity, frequent and extent of soil erosion. These changes may further compound the direct effects of temperature and CO_2, on crop growth and yield.

Relative importance of the impact of climate change versus current climatic variability

While the impact assessment of future climatic change is quite important, most crops in India, even in irrigated environments, are quite sensitive to climatic variability. The latter has considerable effect on the country's food security, despite impressive development of irrigation potential. In field and regional situations, it is not always easy to quantify the impact of climatic variation on food production due to the confounding effects of changing technology used. India had a record harvest of 75.5 Mt of wheat in 1999-2000, an increase of 5 Mt over 1998-1999, with almost the same technology level. This change was largely due to very cool weather during January to March 2000, which was favourable to grain formation and filling. Similarly, the relatively very warm temperatures during March 2004 are expected to result in a production loss of almost 4.0 Mt of wheat. Such variations in food production would be much larger in rice, pulses and oilseeds, where a large portion of the crop area is rainfed. The gluts and shortages of rice, onions and potatoes in recent times, besides being caused by policy and management, are also a manifestation of the effects of climatic variability. If we can evolve strategies for managing climatic variability in agricultural production, adaptation required for climate change would presumably be automatically taken care of.

Adaptation strategies

Any disturbance in agriculture can considerably affect the food systems and thus increase the vulnerability of the large fraction of the resource-poor population. We need to understand the possible coping strategies by different sections and different categories of producers to global climatic change. Such adaptation strategies would need to simultaneously consider the background of changing demand due to globalization, population increase and income growth, as well as the socio-economic and environmental consequences of possible adaptation options. Developing adaptation strategies exclusively for minimizing the negative impact of climatic changes may be risky in view of large uncertainties associated with its spatial and temporal magnitude. We need to identify 'no-regrets' adaptation strategies that may be needed for sustainable development of agriculture. These adaptations can be at the level of the individual farmer, society, farm, village, watershed, or at the national level. Some of the possible adaptation options are discussed below.

Altered agronomy of crops

Small changes in climatic parameters can often be managed reasonably well by altering the dates of planting, spacing and input management. Alternate crops or cultivars more adapted to the changed environment can further ease the pressure. For example, in the case of wheat, early planting or the use of longer duration cultivars may offset most of the losses associated with increased temperatures. Available germplasm of various crops needs to be evaluated for heat and drought tolerance.

Watershed management

Watershed management programmes yield multiple benefits, such as sustainable production, resource conservation, ground water recharge, drought moderation, employment generation and social equity, as is evident from several studies already conducted in different agro-ecological regions of the country. For example, a consistent increase in the production of food grains, fruits as well as in milk, and decline in run-off, soil loss and dependency on forest for fodder and fuel-wood was noticed even after the withdrawal of the active intervention phase in the Fakot watershed project initiated in 1974 (Table 3.5).

Development of resource conserving technologies

Recent research has shown that surface seeding or zero-tillage establishment of upland crops after rice give similar yields as when planted under normal conventional tillage over a diverse set of soil conditions. This reduces the costs of production,

Table 3.5 : Production and protection impact of watershed management programme during pre-project, active Interventions and after withdrawal of interventions (Fakot, Uttaranchal hills, area – 327 ha).

Product	Pre-Project Period (1974-1975)	Average of Intervention Phase (1975-1986)	Average of Post Intervention Phase (1987-1995)
Food Crops (q)	882	4015	5843
Fruit (q)	Neg.	62	1962
Milk ('000 lit.)	56.6	184.8	237.6
Floriculture ('000 Rs.)	Nil	Nil	120.0*
Cash crops ('000 Rs.)	6.5	24.8	202.5
Animal rearing method	Heavily grazing	Partially grazing	Stall feeding
Dependency on forest fodder (%)	60	46	18
Run-off (%)	42	18.3	13.7
Soil loss (t/ha/annum)	11	4.5	2.0

*Community diversified into Floriculture in 1994.

allows earlier planting and, thus, results in higher yields, less weed growth, reduced use of natural resources such as fuel and steel for tractor parts, and improvements in efficiency of water and fertilizers. In addition, such resource conserving technologies restrict the release of soil carbon, thus mitigating the increase of CO_2 in the atmosphere. It is estimated that zero tillage saves at least 30 litres of diesel as compared to the conventional tillage. This leads to 80 kg/ha/year reduction in CO_2 production. If these savings could be translated even partially to large arable areas, substantial carbon dioxide emissions to the atmosphere could be reduced.

Augmenting production and its sustainability

The climatic factors allow very high yield potential of many crops in India. For example, the potential yields of rice and wheat are calculated to be more than six tons/ha whereas their average yields range between two and three tons/ha. Such yield gaps are very large in eastern India and, hence, this region can be a future source of food security for the whole country, under the scenario of adverse climatic impacts. Institutional support in the form of improved extension services, markets and infrastructure need to be provided in such regions to increase stability and bridge yield gaps.

Increasing income from agricultural enterprises

Rising unit costs of production and stagnating yield levels are adversely affecting the incomes of farmers. Global environmental changes, including climatic variability, may further increase the costs of production of crops due to its associated increases in nutrient losses, evapotranspiration and crop-weed interactions. Suitable actions such as accelerated evolution of location-specific fertilizer practices, improvement in extension services, fertilizer supply and distribution, and development of physical and institutional infrastructure, can improve efficiency of fertilizer use.

Improved land use and natural resource management policies and institutions

Adaptation to environmental change could be in the form of social cover such as crop insurance, subsidies, and pricing policies related to water and energy. Necessary provisions need to be included in the development plans to address these issues of attaining the twin objectives of containing environmental changes and improving resource use productivity. Rational pricing of surface and groundwater, for example, can arrest its excessive and injudicious use. The availability of assured prices and infrastructure could create a situation of better utilization of groundwater in eastern India. Policies such as financial compensation/incentive for green manuring should be evolved that would encourage farmers to enrich organic matter in the soil and, thus, improve soil health.

Improved risk management through early warning system and crop insurance

The increasing probability of floods and droughts and other uncertainties in climate may seriously increase the vulnerability of eastern India and of resource-poor farmers to global climate change. Policies that encourage crop insurance can provide protection to farmers in the event their farm production is reduced due to natural calamities. In view of these climatic changes and the uncertainties in future agricultural technologies and trade scenarios, it will be very useful to have an early warning system of environmental changes and their spatial and temporal magnitude. Such a system could help in determining the potential food insecure areas and communities, given the type of risk. Modern tools of information technology could greatly facilitate this.

Recycling waste water and solid wastes in agriculture

Since fresh water supplies are limited and have competing uses, agriculture has to start a vigorous evaluation of using industrial and sewage waste water. Such effluents, once properly treated, can also be a source of nutrients for crops. Since water serves multiple uses and users, effective inter-departmental coordination within the government is needed to develop the location-specific framework of sustainable water management and optimum recycling of water.

Reducing dependence on agriculture

The share of agriculture has declined to 24 per cent of the GDP, but 64 per cent of the population continues to remain dependent on agriculture for its livelihood. Such trends have resulted in fragmentation and decline in the size of land holdings, leading to inefficiency in agriculture and rise in unemployment, underemployment, low volume of marketable surplus and therefore, increased vulnerability to global change. Institutional arrangements, such as cooperatives and contract farming, that can bring small and marginal farmers together for increasing production and marketing efficiencies are needed.

Current programmes, policies, and projects

Some of the initiatives taken by the Government of India including the National Watershed Development Project for Rainfed Areas, improved access to credit for farmers (through *Kisan* Credit Card), creation of a Watershed Development Fund, and implementation of the National Agriculture Insurance Scheme can be considered of importance in adapting to global climatic change. Several schemes, currently being implemented in the Tenth plan (see Box 3.7), are also likely to reduce the vulnerability of agricultural production and conserve soil and water resources (see box for these schemes).

CONCLUSIONS

Changing demands, markets and agricultural technologies are expected to significantly transform Indian agriculture in the near future. The pace of these changes is expected to increase rapidly in the coming years and the whole agricultural scenario may become quite different in the next 10 to 20 years. To address multifarious challenges of sustainable development in the context of future climatic change, agricultural planning has to ensure sufficient food production, employment generation and rural income, while conserving natural resources. Global climatic changes and increasing climatic variability could have some adverse implications in achieving these goals. Therefore, its impact, adaptation measures and vulnerability need to be quantified for different regions. This assessment should include not only crops, but also the livestock and fish sector, important constituents of food supply. We need to develop better scenarios of regional climate change and validated agro-ecosystems models for impact assessment. 'No-regrets' adaptation strategies that would ensure livelihood security for millions of resource-poor small and marginal farmers need cataloguing and implementation. Such an assessment of agriculture and, therefore, policy and technological responses to manage climate change impacts needs an integrated study of biophysical, environmental and socio-economic sectors of agro-ecosystems. This requires unique partnerships, cutting across the barriers of disciplinary/ministerial specialization.

Effective handling of environmental change issues in agriculture also needs a close interaction between scientists, donors, policy makers, administrators, trade

Box 3.7: Thrust Areas for the Tenth Plan in the Agriculture Sector

- Utilization of wastelands and un-utilized/ under-utilized lands.
- Reclamation/ development of problem soils/ lands.
- Rainwater harvesting and conservation for the development of rainfed areas.
- Development of irrigation, especially minor irrigation.
- Conservation and utilization of biological resources.
- Diversification to high value crops/activities.
- Increasing cropping intensity.
- Timely and adequate availability of inputs.
- Strengthening of marketing, processing/value addition infrastructure.
- Revamping and modernizing the extension systems and encouraging the private sector to initiate extension services.
- Bridging the gap between potential and farmer's yields.
- Cost-effectiveness while increasing productivity.
- Promotion of farming systems approach.
- Promotion of organic farming and utilization of organic waste.
- Development of eastern and north-eastern regions, hill and coastal areas.
- Reforms to introduce proactive policies for the farm sector

and industry, farmers' organizations and other stakeholders. Different types of capacity-building programmes need to be developed at various levels to ensure efficient management of natural resources for sustainable agricultural development.

CLIMATE CHANGE IMPACTS ON THE FOREST SECTOR IN INDIA

Importance of Forest Ecosystems in India

India is one of the 12 mega-diversity nations with a rich variety of flora and fauna. It is home to seven per cent of the world's biodiversity and supports 16 major vegetation types, varying from alpine pastures in the Himalayas to temperate, sub-tropical and tropical forests, and mangroves in the coastal areas. The area under forests is estimated to be about 67 Mha according to the State of Forest Reports. In India, about 200 million people depend on forests directly or indirectly for their livelihoods. Forests play an important role in environmental and economic sustainability. They provide numerous goods and services, and maintain life-support systems. In India, deforestation or forest conversion has declined significantly since 1980. However, forest degradation due to fuel wood and timber extraction, livestock grazing and fire, continues. The projected climate change is likely to further exacerbate the socio-economic stresses, leading to adverse impacts on forest ecosystems and forest product flows. Thus, it is very important to assess the impact of projected climate change on forest ecosystems, and develop and implement appropriate adaptation measures.

Some of the major life-support systems of economic and environmental importance of forests are as follows:

Biodiversity: The forests support a wide variety of flora and fauna. More than 5,150 species of plants, 16,214 species of insects, 44 mammals, 42 birds, 164 reptiles, 121 amphibians and 435 fish, are endemic to the country. However, in recent times, heavy biotic pressures have begun to exert tremendous stress on natural resources and, hence, many of the plant and animal species are under various degrees of threat. In order to conserve these, a Protected Area Network, comprising 80 National Parks and 441 Wildlife Sanctuaries have been created on about 14.8 Mha of forests, covering about 4.5 per cent of the geographic area of the country.

Biomass supply: Forests meet nearly 40 per cent of the country's energy needs and 30 per cent of the fodder needs. It is estimated that approximately 270 Mt of fuelwood, 280 Mt of fodder, and over 12 million m^3 of timber and several Non-Timber Forest Products (NTFPs) are removed from forests, annually.

Livelihoods to forest dependent communities: In India there are about 15,000 plant species out of which nearly 3,000 species (20 per cent) yield NTFPs. NTFP activities hold prospects for integrated development that yield higher rural incomes and conserve biodiversity, while not competing with agriculture. Millions of forest dwellers and agricultural communities depend on forests for a range of non-timber forest products, such as fruits, nuts, edible flowers, medicinal herbs, rattan and bamboo, honey and gum. Further, all forest sector activities are labour intensive and lead to rural employment generation.

Gross Domestic Product: The value of goods and services provided by the forest sector is estimated to be Rs. 25,984 crores. Of the GDP of Rs. 23,000 crores, approximately 54 per cent is from fuelwood, 9 per cent is from industrial wood, 16 per cent from NTFPs, and eco-tourism and carbon sequestration account for 14 per cent and 7 per cent, respectively.

Area under Forests and Forest Types in India

Area under forests

The State of Forest Report, 2001, estimates the forest cover in India as 67 Mha, constituting 20.5 per cent of the geographical area. This is composed of 41.7 Mha (12.7 per cent) of dense forest, 25.9 Mha (7.9 per cent) of open forest and 0.4 Mha (0.14 per cent) of mangroves. The forests in India are termed 'dense' if the canopy density is 40 per cent and above, or 'open' if lands have tree cover of canopy density between 10 per cent and 40 per cent. Mangroves are salt-tolerant forest ecosystems, found in inter-tidal regions in estuaries and coasts. There is also 4.73 Mha of scrub in addition to the reported forest cover of 67 Mha.

Forest types in India

According to the Forest Survey of India, the recorded forest area of India has been classified as Reserve Forests, Protected Forests and Unclassed Forests. The area under forests, according to the latest assessment for 2001 is 67 Mha, with reserve forest accounting for about 42 Mha.

Champion and Seth (1935) have broadly classified the forests of India into the following broad categories: (a) tropical forests; (b) montane sub-tropical forests; (c) montane temperate forests; (d) sub-alpine forests; and (e) alpine forests. These have been further classified into 16 sub-types (Figure 3.28). The dominant forest types are the tropical dry deciduous forest (38%) and tropical moist deciduous forest (32%). The other important forest types are tropical evergreen, tropical thorn, sub-tropical pine and alpine forest.

The Forest Survey of India has classified forests into 22 strata, based on the dominant tree species. The dominant forest stratum is the 'miscellaneous' category, accounting for 66 per cent of total forest area, where no dominant species could be identified. Sal, Teak, mixed conifers, upland hardwoods and Bamboo are the other dominant forest strata. The approximate extent of forests on a functional basis is: Protection Forests—10 Mha; Production Forests—15 Mha; Social Forests—25 Mha and Protected Area Network—14.8 Mha. Social Forests here do not include the small blocks of woodlands (less than 25 ha), trees in strips and farms.

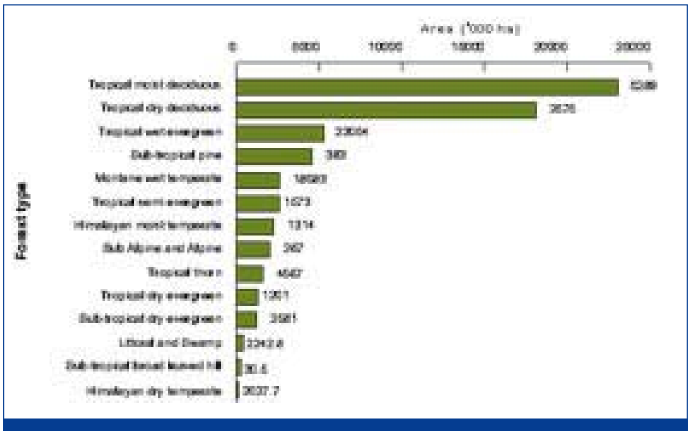


Figure 3.28: Different forest types in India (according to Champion and Seth, 1935).

Methods and Models for Climate Impact Assessment

The models developed to explore the impact of climate change on vegetation fall into two broad categories. Empirical-Statistical models attempt to elucidate the relationship between the existing climate and the existing vegetation. Once such a correspondence is obtained with a reasonable degree of reliability, it is possible to use it to project the distribution of these vegetation types for any future climate scenario. A comparison of such a projected distribution with the existing one can then serve as a basis for assessing the impact of climate change as expected under that scenario. Recently, more sophisticated methods of pattern recognition (for example, the use of neural networks and genetic algorithms), originating in the field of artificial intelligence are also being applied to the problem of impact of climate change. Simulation models explicitly evaluate the temporal changes in the various components of the system (root/shoot biomass, soil moisture levels, concentrations of different pools of nutrients, etc.) from a single step to the next. Equilibrium models predict the final composition, biomass, etc., expected at a location, based on the input parameters (precipitation, temperature, radiation, soil carbon, etc.). Dynamic models, on the other hand, enable one to track the changes expected during the course of the time interval used in the simulation. These models vary greatly in their spatial scales and fundamental processes included in the model, degree of complexity, etc.

Model selected for climate impact assessment; BIOME-3

An impact assessment was carried out using the BIOME-3 model by predicting the equilibrium composition of different vegetation types under the CTL and GHG scenarios.

BIOME-3 model determines equilibrium state vegetation combinations for each location. It combines the screening of biomes through the application of climatic constraints with the computation of net primary productivity (NPP) and leaf area index (LAI), both based on fully coupled photosynthesis and water balance calculations. The underlying hypothesis of the model is that the combination of vegetation types, which is calculated to achieve the maximum NPP, represents the equilibrium vegetation. Using the data on climatic parameters and soil characteristics, the model predicts the potential biome type likely to dominate at a given geographical location.

The climate at the location is specified in terms of mean monthly values of rainfall, temperature and cloud cover (expressed as a percentage). The soil characteristics include the water holding capacity (WHC), depth of the top soil and sub-soil, and the percolation rates. Based on these, the programme calculates the WHC of two layers of soil, 0-500 mm and 500-1500 mm, to be used for the water balance simulation.

The data requirements of BIOME-3 fall into three categories: location, climate and soil. The location information is included in all the climate data files as well, and consists of latitude, longitude and altitude, though the programme does not seem to make use of the input values of longitude and altitude. Only three climatic parameters are required, and mean monthly values of precipitation (mm), temperature (degrees C) and cloud cover (percentage) are supplied in three separate files. The soil parameters needed by the programme are: (a) the Available Water Capacity (AWC) of the top soil; (b) AWC of the sub soil; (c) depth of the topsoil; (d) depth of the subsoil; and (e) percolation rate (though a default value of 30 is used by the programme if data on percolation rate is not available).

The model uses nine Plant Functional Types (PFTs), such as Tropical Evergreen, Tropical Rain green, Temperate Broadleaved Evergreen, Temperate Summer green, Temperate Evergreen Conifer, Boreal Evergreen, Boreal Deciduous, Temperate Grass and Tropical/warm-temperate Grass. Based on the climatic parameters, the model computes the viability and wherever applicable, the productivity-related parameters of the PFTs, such as the LAI and the NPP.

Not all of these biomes are seen in India. Figure 3.29 depicts the distribution of vegetation in India, based on the Champion-Seth classification, which has a reasonably close correspondence with the biome types. The right panel of Figure 3.29 shows the distribution of biome types expected to prevail in India under the climate corresponding to the 'control' run of the HadRM2 model.

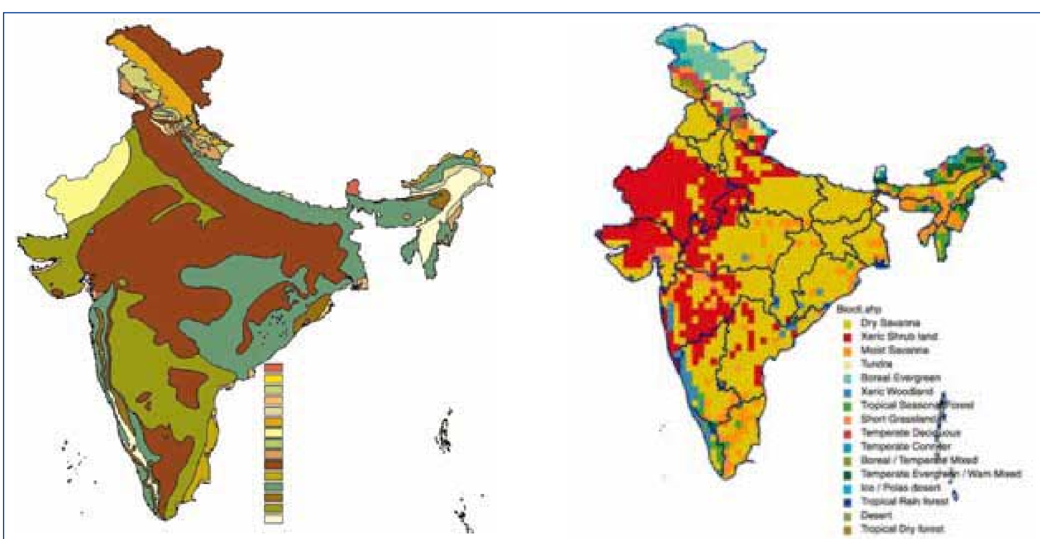


Figure 3.29. Current vegetation map and map for control run of HadRM2.

Choice of climate model and sources of data

Some of the data used in this investigation was obtained from the IPCC Data Distribution Centre. For obtaining monthly mean data, the main entry point of IPCC DDC is *http://ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html.* The two major alternative scenarios suggested by IPCC for which such data is available are the IPCC IS92a emission scenario and the IPCC SRES scenario. Data and information was downloaded from *http://ipcc-ddc.cru.uea.ac.uk/cru_data/datadownload/download_index.html* and used for analysis.

A number of datasets from modelling centres from different parts of the world are available from this site [UK Hadley Centre for Climate Prediction and Research (HadCM2), the German Climate Research Centre (ECHAM4), the Canadian Centre for Climate Modeling and Analysis (CGCM1), the US Geophysical Fluid Dynamics Laboratory (GFDL-R15), the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO-Mk2), the National Centre for Atmospheric Research (NCAR-DOE) and the Japanese Centre for Climate System Research (CCSR)].

The models differ from each other considerably in grid size or resolution. Many of them consider rather coarse grids, with one or both of longitude/latitude greater than four degrees. The two models with the best resolution are HadCM2 (3.75 × 2.5 degrees) and ECHAM4 (2.8125 × 2.8125 degrees), and seemed the most appropriate for the present investigation. The kinds of variables generated and made available by these models also differ from each other. Of these two models, the climate variable 'percentage of cloud cover' (required to obtain the value of 'percentage of sunshine hours' needed to run the BIOME-3 programme), was available only for the HadCM2. Second, the data at even finer (regional) scale (0.4425 × 0.4425 degrees) was available for HadRM2, derived from HadCM2. Projections from HadCM2 model have been used for analysis.

The RCM is obtained by downscaling from the boundary conditions of the GCM, and uses a much finer spatial (0.4425 degrees in longitude as well as latitude, corresponding approximately to a 50 km × 50 km grid), as well as temporal (daily) resolution. However, data for this model available only for a smaller duration, corresponding to the years 2041 to 2060, both for control as well as GHG Scenario 1. No data is available as yet for Scenario 2. The RCM dataset also contains fewer parameters (for example, only maximum and minimum temperature and not the average temperature separately).

In addition to the above, actual climate data (monthly values from 1901 to about 1995) for the Indian region, compiled by the Climate Research Unit of the University of East Anglia, also at a fine (0.5 degrees × 0.5 degrees, comparable to the RCM) spatial resolution, was also made use of in the present analysis.

Vulnerability of Forest Ecosystems in India to Projected Climate Change

The approach used in the present investigation for exploring the vulnerability of forest ecosystems to projected climate change is based on the application of BIOME-3 model to about 1500 grids (50 km × 50 km) across the Indian region. The climate-related parameters for these grids are from the HadRM2. The soil parameters for a grid were obtained from the nearest of the 78 locations for which soil data was available. (in fact, the sensitivity of the results to the soil parameters was also investigated by assigning several different soil parameters to the grids; the predictions were found to be quite robust). The outputs of the BIOME-3 (biome type, net primary productivity, etc. using climate from the control run of RCM indicated the current situation, while that from the GHG run described the vegetation that was likely to prevail around 2050 under the GHG Scenario. The differences in the outputs of BIOME-3 at each of the grids were used for assessing the direction and extent of the expected change in the vegetation.

The analysis is primarily based on the HadCM2 model, and on the scenario corresponding to one per cent compounded annual increase in CO_2 concentration. This led to about 3.4 °C increase in the average annual temperature over the Indian region by 2050. However, when effects of aerosols/sulfates were included in the same scenario, HadCM2 showed a smaller increase, of 1.89 °C, for the same region for the same year. The other, milder scenario, with 0.5% annual increase of CO_2 showed an increase of 2.3 °C without sulfates and 2.0 °C with sulfates. Thus, all the three remaining scenarios are likely to lead to less severe changes in vegetation and in the shifts of forest boundaries than obtained in the present analysis. It is even more difficult to draw any inference based on the changes in the precipitation, since there does not seem to be any direct correlation between the changes in temperature and those in the precipitation for the Indian region—all the four cases show a small overall decrease in the rainfall.

It is possible that this is an artifact of the coarse grid of GCM, since the HadRM2 with a finer grid does show a slight increase in the rainfall expected over the Indian region by 2050. Further, HadCM2 is one of the several GCMs. There is a variation in the projections of climate parameters (such as temperature and precipitation) among GCMs, though all GCMs project warming and changes in precipitation patterns across all regions.

The expected distribution of biome types in India is shown in Figure 3.30 for the climate projected to prevail over India during 2041-2061 under the GHG scenario. The large-scale changes in the vegetation types are immediately evident from the figure (right panel of Figure 3.30 when compared to the vegetation types prevailing today (left panel of Figure 3.30). These changes are along the lines expected, on the basis of increase in CO_2, as well as the changes in rainfall and temperature described in the previous sections.

Shifts in major forest types considering all grids and potential vegetation

While Figure 3.31 brings out the spatial distribution of projected changes in forest biome types, the quantitative estimates can be obtained on the basis of the number of RCM grids (out of a total of about 1500) that change from one biome type into another. A very large proportion (about 70 per cent) of the grids (and concomitantly, existing forests) are likely to experience a change. It is worth emphasizing here that large changes are possible for some of the biomes, even though the total aggregate area under these does not show any change during this period. This is because the locations of the biome show conspicuous shifts due to the marked changes in the climatic conditions.

The biome type most seriously impacted is the Dry Savanna. About 62 per cent of it, mainly lying in the northern/central parts of India, is likely to be converted into Xeric Woodland (Dry Thorn Forest), while another 24 per cent, mainly in the north-western parts, is likely to change to Xeric Shrubland. In general, increased CO_2 is expected to lead to an

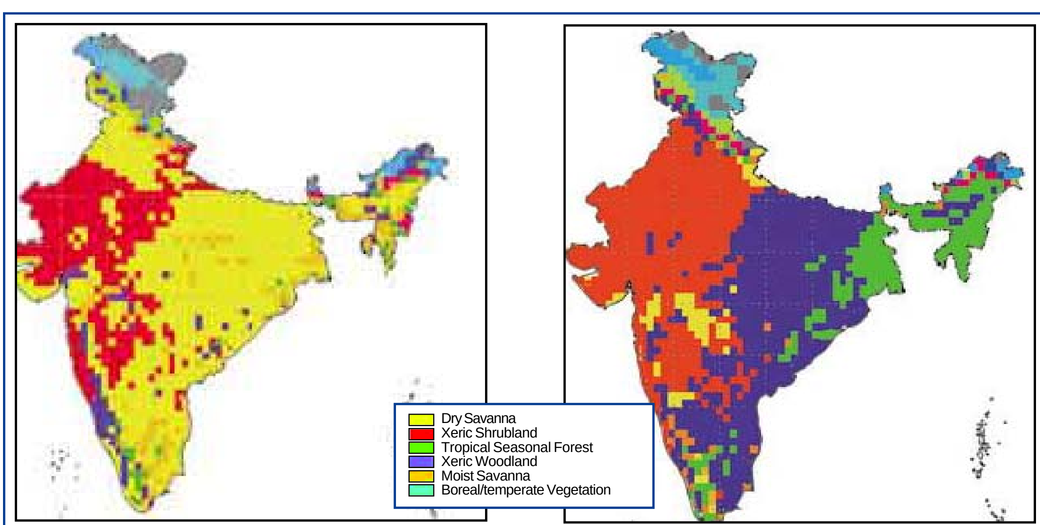


Figure 3.30. Vegetation map for year 2050, GHG run of HadRM2 considering all grids of India and potential vegetation (including grids without forests). The control run is shown in the left panel.

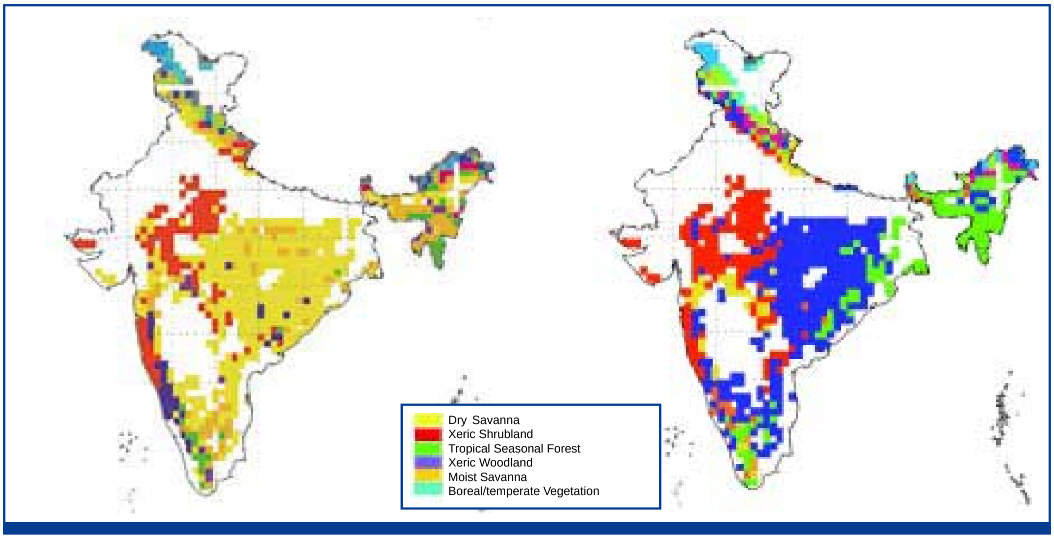


Figure 3.31: Vegetation map of India for 2050 including only the grids that have forests at present.

increase in the NPP (as will be discussed later). This has an effect of converting grassland into woodlands and woodlands into forests. Thus, in regions with a relatively large temperature increase, dry and moist savannas are likely to be replaced by xeric vegetation, while in the areas with a lower temperature increase and enhanced rainfall, the moist savannas seem to be transformed into Seasonal Tropical Forests. However, the northern part of the country has largely been transformed into agricultural land and thus the savannas occupy only a small geographical area.

The other biome type to be affected is the moist savanna located in the north-east and some parts of southern India. This is likely to be converted into Tropical Seasonal Forest (about 56 per cent), mostly in the north-east and Xeric woodland (Dry Thorn Forest) (about 32 per cent) mostly in southern India, depending on the change in the quantum of rainfall. The Tropical Seasonal Forest, especially in the north-east, is likely to change into Tropical Rain Forest due to a large increase in rainfall expected to take place in that region.

The changes expected in the colder regions are also along similar lines, with the Tundras likely to change to boreal evergreens, and boreal evergreens into temperate conifers.

Shifts in major forest types considering grids with forests: As mentioned earlier, the above results were based on the analysis of the potential forest cover. To make a more realistic assessment of the likely impact of projected climate change on forests, the analysis was repeated by confining it to actual locations of forests. This was made using the map provided by the Forest Survey of India. This map divides the Indian region into grids of 2.5 × 2.5 minutes and provides information on the type and density of forest in the grid. This is at a much finer scale than the RCM grid (about 26 × 26 minutes), and each of the RCM grids contains about 160 grids of the Forest Survey of India map. A detailed examination of this map showed the presence of forests in about 800 of the 1500 RCM grids.

The distribution of forest types obtained in these 800 grids under the control run is shown in the left panel of Figure 3.31, while that obtained for the GHG run (for the year 2050) is shown in the right panel of Figure 3.31. Interestingly, the results obtained from the analysis based on these 800 grids were very similar to the ones reported for the 1500 grids. Thus, changes in forest types were seen in about 600 out of the 800 forested grids (75 per cent), as compared to a figure of 70 per cent obtained for the analysis based on 1500 grids. The biome type likely to be most seriously impacted continues to be the Dry Savanna, and about

70 per cent of it is likely to be converted to Xeric Woodlands, and about 15 per cent to Xeric Shrubland. These estimates are similar to the 62 per cent and 24 per cent obtained earlier for the corresponding changes. The other forest type likely to be affected is Moist Savanna, with 56 per cent of grids likely to be converted into Tropical Seasonal Forest and 28 per cent into Xeric Woodlands, again very similar to the estimated changes of 56 per cent and 32 per cent obtained earlier.

In summary, more realistic estimates of impacts obtained by running the BIOME3 model only on the 800 grids corresponding to forested regions are seen to be qualitatively and quantitatively very similar to the ones obtained for the full Indian region (1500 grids), thus highlighting the robustness of the trends inferred from the analysis.

Implications for biodiversity: Independent of climate change, biodiversity is forecast to decrease in the future due to multiple pressures, in particular, increased land-use intensity and the associated destruction of natural or semi-natural habitats. While there is little evidence to suggest that climate change will slow species losses, there is evidence that it may increase species losses. Changes in phenology are expected to occur in many species. The general impact of climate change, is that the habitats of many species will move poleward or upward from their current locations. Species that make up a community are unlikely to shift together. Ecosystems dominated by long-lived species (for example, long-lived trees) will often be slow to show evidence of change and slow to recover from climate-related stresses.

Qualitative observations about the likely impact of climate change on wildlife species were made. If woody plants including exotic weeds invade montane grasslands of the Western Ghats, there would be serious consequences for the endemic Nilgiri *tahr*. Upward altitudinal migration of plants in the Himalayas could reduce the alpine meadows and related vegetation, thus impacting the habitats of several high altitude mammals including wild sheep, goat, antelope and cattle. An increase in precipitation over north-eastern India would lead to severe flooding in the Brahmaputra and place the wildlife of the Kaziranga National Park at risk. Any large-scale change in vegetation to drier types over central and north-western India would also have consequences for the fauna of these regions.

Implications for NPP, growing stock (biomass) and regeneration: At the global level, net biome productivity appears to be increasing. Modelling studies, inventory data and inverse analyses provide evidence that, over the past few decades, terrestrial ecosystems have been accumulating carbon. The mean NPP (grams of carbon per square metre per year) was about 338 in the control run, with a maximum value around 1,049. By 2050, as per the BIOME model, these values are likely to show a considerable increase. The mean value reaches about 435 (more than 25 per cent increase) while the maximum reaches about 1,400 (more than 30 per cent increase). In fact, more than 75 per cent of the grids show an increase in NPP. As expected, the grids showing a decrease in NPP lie in the northwestern region where a deficit in rainfall, and a large increase in temperature are expected. However, this region has a rather low value of NPP (about 230), and the projected decrease is also rather small (about 13 per cent).

Vulnerability of Forest Ecosystems in India and Socioeconomic Impacts

Thus, even in the relatively short span of about 50 years, most of the forest biomes in India seem to be highly vulnerable to the change in climate. As estimated earlier, about 70 per cent of the locations are expected to experience a change in the prevailing

Project Tiger is a major initaitive of the Government of India for wildlife management, protection measures and site specific ecodevelopment.

biome type. In other words, about 70 per cent of the vegetation is likely to find itself less optimally adapted to its existing location, making it more vulnerable to the adverse climatic conditions as well as to the biotic stresses, which it is subjected to from time to time. As a result, during the process of take-over of one biome type by another, large-scale mortality might be expected.

The actual negative impact may be more than what is initially expected from the above description. This is because different species respond differently to the changes in climate. So, even in the region where there is no shift in the biome type, changes in the composition of the assemblages are certainly very likely. Thus, one expects that a few species may show a steep decline in population and perhaps result in local extinctions. This, in turn, will affect the other taxa dependent on the different species (i.e., a 'domino' effect) because of the interdependent nature of the many plant-animal-microbe communities that are known to exist in forest ecosystems. This could eventually lead to major changes in the biodiversity.

The north-western region of the country seems to be more vulnerable to climate change, since it is likely to experience the effect of two negative influences: a large temperature increase together with a decrease in precipitation. The vulnerability of the north-eastern region stems from a very different cause. The major increase in precipitation expected in this region is likely to shift the vegetation towards the wetter, more evergreen vegetation. Since these are rather slow growing, the replacement will take much longer, and increased mortality in the existing vegetation may lead to a decrease in the standing stock.

Uncertainty of projected impacts

GCMs are more robust in projecting global mean temperatures compared to their ability for making predictions at the regional levels. The uncertainty involved in projections of temperature and particularly precipitation at regional level is high. The vegetation response model BIOME-3 is an equilibrium model and does not project the transient phase responses. Also, the database on soil, water and plant physiological parameters as input to vegetation models such as BIOME-3, is poor. Thus, the findings

Reforestation programmes enhance the sequestration potential of forests.

of the present analysis should be viewed with caution. Though there is some uncertainty on the magnitudes of the projections of change, and though these may also vary with GCMs and RCMs used, the direction of change is unlikely to be different.

Socio-economic impacts: Nearly 200,000 villages in India are situated in or on the fringe of forests. Further, about 200 million people depend on forests for their livelihood, directly or indirectly. Forest ecosystems in India are already subjected to socio-economic pressures leading to forest degradation and loss, with adverse impacts on the livelihoods of forest dependent communities. Climate change will be an additional pressure on forests, affecting biodiversity as well as biomass production. According to the assessment of projected climate impacts on forests, significant changes in the forest boundary of different forest biomes as well as biodiversity are projected. However, during the transient phase, large-scale forest die-back may occur. This may affect the production and supply of non-timber forest products to the forest dependent communities, affecting their livelihoods. In the transient phase, there could be an increased supply of timber, due to forest die-back, depreciating timber prices.

Forest Policies and Programmes–Vulnerability of Forest Ecosystems

Forest policies in any country determine the status of forests; rates of deforestation and afforestation, levels of fragmentation, conservation and protection, and

Chapter 1 Chapter 2 Chapter 3 Chapter 4 Chapter 5 Chapter 6 Chapter 7

rates of timber and non-timber extraction. The vulnerability of forest ecosystems to climate change depends on the status of forests, biodiversity, fragmentation, afforestation practices, rates of extraction of timber, etc. For example, forest fragmentation may enhance vulnerability and decrease the adaptation capacity of forest ecosystems to climate change, whereas biodiversity conservation may reduce vulnerability.

India has formulated and implemented a large number of legislations, and forest conservation and reforestation programmes. These programmes have contributed towards: (a) stabilization of area under forests with marginal rates of deforestation, even though forest degradation may be continuing; (b) producing fuelwood and industrial wood, thereby reducing pressure on the forests; and (c) involvement of local communities in protection and management of forests, even though there is inadequate empowerment of community institutions.

Forest policies, programmes and practices that enhance vulnerability to climate change

Some of the policies, programmes and practices that potentially contribute to enhancing the vulnerability of forest ecosystems to climate change are as follows:

- Forest fragmentation leading to loss of biodiversity by hampering migration of species.
- Forest degradation leading to loss of biodiversity, affecting forest regeneration.
- Dominance of monoculture species under afforestation increase vulnerability to fire, pests, etc.
- Absence of fire protection and management practices enhance vulnerability to fire.
- Non-sustainable extraction of timber, fuelwood and NTFPs leading to degradation of forests, fragmentation of forests and affecting shift of forest boundaries and regeneration of plant species.
- Inadequate fuelwood conservation programmes increases pressure on forests, leading to degradation.
- Inadequate and less-effective implementation of the different conservation programmes leading to forest degradation.

There is a need for research studies to identify and assess the implications of policies and programmes to vulnerability of forest ecosystems.

Forest policies, programmes and practices reducing forest vulnerability

India has implemented a large number of forest conservation and development programmes that have the potential to reduce the vulnerability of forest ecosystems to impacts of climate change.

- The forest Conservation Act 1980, Wild Life Act, Protected Areas and other policies contribute to forest and biodiversity conservation and reduction of forest fragmentation.
- A large afforestation programme has reduced the pressure on forests for timber, industrial wood and fuelwood, leading to conservation of biodiversity and reduction of forest degradation.
- Involvement of local communities in forest protection and regeneration and creation of long-term stake in forest health, through the Joint Forest Management (JFM) programme.

The performance and impacts of these measures in quantitative terms are however not clear.

Adaptation Policies, Programmes and Practices

Why adaptation in forest sector?

The preliminary assessment of the impact of projected climate change, based on BIOME-3 outputs, indicates shifts in forest boundaries, replacement of current assemblage of species, leading to forest die-back. The need for adaptation measures to minimize the adverse impacts is strengthened due to the following reasons:

- The impacts such as loss of biodiversity are long-term and irreversible.
- There is inertia and a lag period between climate change and impacts.
- Long-term planning is necessary for forest conservation, afforestation and silvicultural practices to impact on forest regeneration and biodiversity.
- Large forest-dependent rural population and potential adverse impacts on their livelihood.

- Inadequate technical, institutional and financial capacity to adapt to climate change impacts in the forest departments, as well as at the forest dependent community level.

Policies, programmes and practices to promote adaptation

The current state of science has several limitations, particularly in projecting climate change at the regional level and assessing the response of diverse tropical forest vegetation to projected climate parameters. The vegetation models such as BIOME-3 do not incorporate the adaptation response component. Thus, at the current state of knowledge and the uncertainties involved, only 'no regret' or 'win-win' and a few 'precautionary' adaptation policies, programmes and practices could be considered. Some examples of such measures are listed here.

Forest policies: India has formulated a large number of innovative and progressive forest policies, which have the potential to reduce vulnerability. Some examples of policies, which need effective implementation, are as follows:

- Incorporate climate concern in along-term forest policy-making process.
- Incorporate climate concern in the forest 'working plan' process to enable incorporation of silvicultural practices to promote adaptation.
- Improve and ensure the effective implementation of existing policies/Acts/guidelines such as:
- Forest Conservation Act, 1980; Wildlife Protection Act, 1972 and 2002; enhance coverage and effectiveness of protected area; wildlife conservation programmes such as Project Tiger and Project Elephant.
- Link Protected Areas, Wildlife Reserves and Reserve Forests.
- Enhance support to afforestation and reforestation programmes and increase area covered to increase the production of timber and fuelwood to reduce pressure on primary forests.

Forestry and silvicultural practices: Current afforestation and silvicultural practices dominated by exotics and monocultures are enhancing the vulnerability of forests. Some of the potential silvicultural practices that could reduce vulnerability and enhance resilience are:

- The promotion of natural regeneration in degraded forest lands and mixed species forestry on degraded non-forest lands.
- The anticipatory planting of species along the latitudinal and altitudinal gradient.
- The *in-situ* and *ex-situ* conservation of plant and animal species.
- The implementation of fire prevention and management practices.
- The adoption of short rotation species and practices.
- The adoption of sustainable harvest practices for timber and non-timber products.

There is a growing need for research to identify the silvicultural practices which reduce vulnerability of forest ecosystems to changing climate parameters.

Institution and capacity building to address climate change in forest sector: India has institutions with significant infrastructure and technical capacity. However, these institutions have not focused on climate change research, which includes modelling, field ecological studies and laboratory experimentation. There is a need to create awareness and enhance technical and institutional capacity in the research institutions, forest department and NGOs. Forest dependent communities have poor financial, technical and institutional capacity to adapt to adverse impacts of climate change. Thus, it is necessary to enhance the capacity of those forest-dependent communities who are likely to be vulnerable to projected climate impacts.

Conclusions

A preliminary assessment using the BIOME-3 vegetation response model, based on regional climate model projections for India showed shifts in forest boundary, changes in species-assemblage or forest types, changes in NPP, possible forest die-back in the transient phase, and potential loss or change in biodiversity. These impacts on forests will have adverse socio-economic implications for forest-dependent communities and the national economy. The impacts of climate change on forest ecosystems are likely to be long term and irreversible.

There is a need for developing and implementing adaptation strategies to minimize the adverse impacts. Further, there is a need to study and identify the forest policies, programmes and silvicultural practices that contribute to vulnerability of forest ecosystems to climate change.

India needs to initiate studies to identify forest strategies, policies, silvicultural practices and institutional arrangements that enhance forest resilience and reduce vulnerability.

India should initiate long-term dedicated research, monitoring and modelling programmes to study vegetation responses to climate change, generate regional climate projections, improve dynamic vegetation models and their application, and conduct policy analysis to develop adaptation strategies.

CLIMATE CHANGE IMPACTS ON NATURAL ECOSYSTEMS

The large geographical area, varied topography and climatic regimes, long coastline and the possession of oceanic islands, have endowed India with a diversity of natural biomes from deserts to alpine meadows, from tropical rainforest to temperate pine forests, from mangroves to coral reefs, and from marshland to high-altitude lakes. The natural ecosystems have also been subject to exploitation and alteration by humans for several thousand years, and thus only a small fraction of these probably remain in a pristine state. Nevertheless, about one-fifth to one-fourth of the geographical area still comprises relatively 'natural' ecosystems; of this, forests occupy the major area. The non-forest ecosystems include mainly the wetlands (including mangrove forests and coral reefs) and the grasslands. The assessment of impacts of projected climate change on natural ecosystems is not based on modeling or field studies, but on current vulnerability and global-level projection of impacts from literature.

Wetlands

The natural wetland ecosystems of India include the marine ecosystems such as the coral reefs; coastal ecosystems such as the mangroves; and inland fresh-water ecosystems such as rivers, lakes and marshes. The most comprehensive wetland inventory of India that is available at present, is that prepared by the Space Application Centre (SAC) of the Indian Space Research Organization, using satellite imagery for the years 1991-1992. This inventory has listed 27,403 wetland units occupying a total area of 75,819 km^2, with the coastal wetlands comprising 53 per cent and the rest being inland wetlands.

Marine ecosystems (Mangroves and coral reefs)

The Indian coastline is over 7,500 km, and including the islands of Lakshadweep and the Andaman and Nicobars. As many as 3,959 coastal wetland sites, classified under 13 major wetland types, and covering a geographical area of 40,230 km^2 have been mapped by the Space Application Centre across nine states and four Union Territories. Of these, 426 sites (1,424 km^2) are man-made wetlands (salt pans and aquaculture ponds) and the rest are natural coastal wetlands. (Table 3.6).

The coastal wetlands play an important role in the economy of this region, especially in fisheries. The mangroves and the coral reefs in particular are important nurseries for several fishes, prawns and crabs. Of the annual fish catch of about 5.6 Mt, about half is from marine fisheries; the coral reefs and associated shelves and lagoons alone have the potential for about 10 per cent of the total marine fish yields. Climate change impacts on the coastal wetlands would thus have serious consequences for the livelihoods of people, as well as the integrity of the coastal environment.

Mangroves

Mangroves are mainly distributed along the east coast of the country and to a lesser extent along the west coast. The Sunderbans, covering an area of about 10,000 km^2 along the Ganges-Brahmaputra delta, constitute the largest mangrove wetland in the world; of this area, about 40 per cent is found in West Bengal and the rest in Bangladesh. Other important mangroves include the Mahanadi mangrove in Orissa, the Godavari and Krishna mangroves in Andhra Pradesh, the Pichavaram and Muthupet mangroves in the Cauvery delta of Tamil Nadu, the mangroves in the Gulf of Kutchh in Gujarat, and those in the Andaman and Nicobar islands.

Table 3.6: Area under various coastal and inland wetland types.

Types of Coastal Wetlands	Area (sq. km)	Inland Wetland Category	Number	Area (sq. km)
Tidal Mudflats	23,621	Natural		
Mangroves	4,871	Lakes/Ponds	4646	6795
Estuaries	1,540	Ox-bow lakes	3197	1511
Lagoons	1,564	Waterlogged (Seasonal)	4921	2857
Sand Beaches	4,210	Playas	79	1185
Marshes	1,698	Swamps/Marshes	1814	1978
Other Vegetated Wetlands	1,391	Man-made		
Coral Reefs	841	Reservoirs	2208	14820
Creeks	192	Tanks	5549	5583
Backwaters	171	Waterlogged	892	773
Rocky Coasts	177	Abandoned Quarries (water)	105	58
Salt-Pans	655	Ash ponds/Cooling ponds	33	29
Aquaculture Ponds	769	Total Inland Wetlands	23444	35589

Source: Space Application Centre.

With the exception of the mangroves of the Andaman and Nicobars, the mangroves of the country are already considerably degraded. The development of agriculture in the deltas of the major rivers, the reclamation of the coastal wetland for settlement and the use of mangroves to supply products such as fuel-wood have resulted in considerable shrinkage of the mangrove areas. According to one estimate the mangrove cover of the country reduced by 35 per cent during the period 1987-1995 alone (estimate made by Sustainable Wetlands, Environmental Governance-2 in 1999).

The mangroves are at risk due to direct human activities as well as due to climate change.

Climate change impacts on the mangrove ecosystems would be governed by factors such as sea-level changes, storm surges, fresh-water flows in rivers both from precipitation in their catchments as well as from snow melt in the mountains, local precipitation, and temperature changes that would influence evapotranspiration. Sea-level rise would submerge the mangroves as well as increase the salinity of the wetland. This would favour mangrove plants that tolerate higher salinity. At the same time, increased snow melt in the western Himalayas could bring larger quantities of fresh water into the Gangetic delta. This would have significant consequences for the composition of the Sundarbans mangroves. Changes in local temperature and precipitation would also influence the salinity of the mangrove wetlands and have a bearing on plant composition. Any increase in freshwater flows would favour mangrove species that have the least tolerance to salinity.

It is therefore, necessary to model the specific scenarios for the various mangrove ecosystems using climate change projections, changes in freshwater and sediment flows, geomorphology, sea-level change and the land use of the coastal region.

Coral reefs

Coral reefs are distributed in six major regions along the Indian coastline. These are the Gulf of Kutchh in

Gujarat, the Malwan coast in Maharashtra, the Lakshadweep islands, Gulf of Mannar and Palk Bay in Tamil Nadu, and the Andaman and Nicobar islands. Built up during the Tertiary and the Quaternary Periods, the coral reefs in the Indian Ocean include sea level atolls (Lakshadweep archipelago), fringing reefs (Gulf of Mannar, Palk Bay, and Andaman and Nicobars), reef barriers (Andaman and Nicobars), elevated reefs and submerged reef platforms.

The biodiversity of the coral reefs includes a variety of marine organisms, including sea grasses, corals, several invertebrate groups, fishes, amphibians, birds (nesting on the reefs) and mammals. The reefs of the Andaman and Nicobar islands have the highest recorded diversity with 203 coral species, 120 algal species, and 70 sponges in addition to fishes, sea turtles, dugong and dolphins. About 1,200 species of fishes have been recorded in the seas around the islands, including 571 species of reef fish. The reefs of the Gulf of Mannar and Lakshaweep islands have intermediate levels of diversity, with 117 species and 95 species of hard corals respectively. The Gulf of Kutchh is the least diverse, with only 37 species of corals and the absence of ramose forms.

The coral reefs in the Indian region are already under threat from several anthropogenic and natural factors, including destructive fishing, mining, sedimentation, and invasion by alien species. To this we must add the possible impacts of future climate change.

It is well known that increased sea surface temperature (SST) results in 'bleaching' of corals. While bleaching is a normal event and is reversible, a prolonged increase in SSTs and/or intense bleaching may result in the death of the corals. In recent decades, the most widespread and intense bleaching of corals ('mass bleaching'), including in the Indian Ocean, occurred during the years 1997-1998 associated with *El Nino* when SSTs were enhanced by over 3° C, the warmest in modern record. While the coral reefs of India too were adversely affected, the precise extent of bleaching and mortality of corals is not clear in many regions.

Coral bleaching due to warming.

The corals of the Lakshadweep islands were, however, significantly affected by this event with bleaching of over 80 per cent of coral cover and mortality of over 25 per cent of corals. The corals of the Gulf of Mannar were similarly affected. The most affected were shallow water corals, such as the branching *Acopora* and *Pocillopora* that were almost completely wiped out. Bleaching also affected the massive corals but these recovered and now dominate the reefs. The least affected coral reefs were those in the Gulf of Kutchh with an average of about 10 per cent bleaching and little mortality.

Inland or freshwater wetlands

The inland wetlands include a large number of natural lakes and swamps or marshes, as well as man-made reservoirs and tanks.

The SAC inventory lists 23,444 inland wetland units covering an area of 35,589 km^2 in total. Of these, the natural inland wetlands numbering 14,657 units cover an area of 14,326 km^2, are relevant to the discussion of climate change impacts. It must also be remembered that some of the man-made wetlands such as at Bharatpur in Rajasthan are exceptionally rich in bird species and should be considered as a natural wetland for the purpose of conservation in the face of climate change.

As in many other parts of the world, the inland wetlands of India have been transformed by draining for urban settlement, agricultural development, construction of roads, exploitation for their resources, and pollution from a variety of sources. A study by the Wildlife Institute of India showed that 70-80 per cent of freshwater marshes and lakes in the Gangetic floodplains have been lost over the past five decades.

Pollution of the wetlands is mainly from the discharge of sewage, industrial effluents, agricultural chemicals such as pesticides and fertilizers, and sedimentation from soil erosion.

Climate change impacts on the inland wetlands would be a complex issues dependent on several variables, including temperature increase, rate of evaporation, changes in precipitation of the catchment, changes in nutrient cycling and the responses of a variety of aquatic species. Although tropical lakes are less likely to be impacted by climate change as compared to temperate lakes, an increase in temperature would alter the thermal cycles of lakes, oxygen solubility and other compounds, and affect the ecosystem. In high-altitude lakes an increased temperature would result in the loss of winter ice cover; this would cause a major change in the seasonal cycle and species composition of the lake. Reduced oxygen concentration could alter community structure, characterized by fewer species, especially if exacerbated by eutrophication from surrounding land use. Lake-level changes from increased temperature and changes in precipitation would also alter community structure.

Shallow-water marshes and swamps would be even more vulnerable to increased temperatures and lower precipitation as projected for central and north-western India by the Hadley Centre's HADCM2. The increased evaporation of water and reduced inflow from rainfall could desiccate the marshes, swamps and shallow lakes.

Grasslands

There are five major grassland types recognized in India, on the basis of species associations, geographical location and climatic factors. These are: (a) alpine grasslands of the Himalayas; (b) moist fluvial grasslands of the Himalayan foothills; (c) arid grasslands of northwestern India; (d) semi-arid grasslands of central and peninsular India; and (e) montane grasslands of the Western Ghats

The same anthropogenic factors such as livestock grazing and fire that were responsible for creating many of the grassland types in the country are also involved in their degradation. While moderate levels of grazing could be sustainable and even promote plant species diversity, heavy grazing reduces the plant cover and eliminates palatable grasses and herbs while promoting the growth of unpalatable plants.

When considering the likely impact of future climate change on natural grasslands, we need to consider several factors including the direct response of grasses to enhanced atmospheric CO_2, as well as changes in temperature, precipitation and soil moisture. It is well known that plants with the C3 and the C4 pathways of photosynthesis respond differently to atmospheric CO_2 levels and also to temperature and soil moisture levels. The C3 plants include the cool, temperate grasses and practically all woody dicots, while the C4 plants include the warm, tropical grasses, many sedges and some dicots. The C4 plants that constitute much of the biomass of tropical grasslands, including the arid, semi-arid and moist grasslands in India, thrive well under conditions of lower atmospheric CO_2 levels, higher temperatures and lower soil moisture, while C3 plants exhibit the opposing traits. Increasing atmospheric CO_2 levels should, therefore, favour C3 plants over C4 grasses, but the projected increases in temperature would favour the C4 plants. The outcome of climate change would thus be region-specific and involve a complex interaction of factors.

GCM model projections (for example, the HADCM2) for India indicate an increase in precipitation by up to 30 per cent for the north-eastern region in addition to a relatively moderate increase in temperature of about 2° C by the period 2041-2060. This could increase the incidence of flooding in the Brahmaputra basin and thus favour the maintenance of the moist grasslands in the regions. The HADCM2 projections for the rest of the country (southern, central and north-western India are a steep increase in temperature of 3° C in the south (except along the coast) to over 4° C in the north-west, and a decrease in precipitation of over 30 per cent in the north-west though little change in parts of the south. This combination of temperature increase and rainfall decrease would cause major changes in the composition of present-day vegetation in these regions, with an overall shift to a more arid type. Increased atmospheric CO_2 levels and temperatures, resulting in lowered incidence of frost, would favour C3, plants including exotic weeds such as wattle (*Acacia spp.*) that could invade the montane grasslands of the Western Ghats. The cool, temperate grasslands of the Himalayas could also be impacted by rising temperatures that would promote the upward migration of woody plants from lower elevations.

An assessment of climate change impacts on natural ecosystems would require a systematic programme of documenting ecosystem processes, modelling climate change impacts and formulating strategies for adaptation.

CLIMATE CHANGE IMPACTS ON COASTAL ZONES

Indian Coastal Zones and climate change

The coastal zone is an important and critical region for India. This region is densely populated and stretches over 7,500 km, with the Arabian Sea on the west and the Bay of Bengal on the east. It is inhabited by more than a 100 million people in nine coastal states (West Bengal, Orissa, Andhra Pradesh and Tamil Nadu on the east coast, and Kerala, Karnataka, Goa, Maharashtra and Gujarat on the west coast), two UTs (Pondicherry and Daman and Diu) and two groups of islands (Andaman and Nicobars, and Lakshdweep). According to the census of 2001, there were about 65 coastal districts in these nine states. The total area occupied by the coastal districts is around 379,610 km^2, with an average population density of 455 persons per km^2, which is about 1.5 times the national average of 324 (Census, 2001). The Indian coastline can be categorized into three classes—coast of emergence, coast of submergence and neutral coast (Table 3.7).

The western coastline has a wide continental shelf with an area of about 0.31 million km^2, which is marked by backwaters and mud flats. East coast is flat, deltaic and rich in mangrove forests. Mangroves are located all along estuarine areas, deltas, tidal creeks, mud flats, salt marshes and extend to about 6740 km^2. Major estuarine areas located along the Indian coasts extend to about 2.6 million hectares. Coral reefs are predominant on small islands in Gulf of Kutchh, Gulf of Mannar in Tamil Nadu and on Lakshadweep and the Andaman and Nicobar islands. Ecosystems such as coral reefs, mangroves, estuaries and deltas are rich in biodiversity. These ecosystems play a crucial role in fishery production in addition to protecting the coastal zones from erosion by wave action. There are 11 major and 130 minor sea ports located in coastal zones that are economic engines of international and national trade and commerce in India.

Future climate change in the coastal zones is likely to be manifested through the worsening of some of the existing coastal zone problems. Some of the main climate-related problems in the context of the Indian coastal zones are erosion, flooding, subsidence, deterioration of coastal ecosystems, such as mangroves, and salinization. In many cases, these problems are either caused by or exacerbated by sea level-rise and tropical cyclones. The key climate-

Table 3.7: Physiographic characteristics of the Indian coastline.

Coastline part	Coastline type
North-east coast (West Bengal, Orissa and parts of Andhra Pradesh)	Emerging coastline with no offshore bar
Shoreline off the mouths of Ganga, Mahanadi, Krishna, Godavari and Cauvery Rivers	Neutral and highly dynamic (due to the large influx of sediments) coastline
Southeast coast (Tamil Nadu and parts of AP)	Emerging coastline with an offshore bar and lagoon
Southwest coast (Kerala)	Submerging coastline (highly-indented shoreline with an erosional tendency)
Mid-west coast (Karnataka, Goa, Maharashtra)	Submerging coastline (network of coastal rivers, inland creeks, backwaters and rocky headlands)
North West coast (Gujarat)	Submerging coastline (creeks and inland waters)

Source: NIO

related risks in the coastal zone include tropical cyclones, sea-level rise, and changes in temperature and precipitation in the context of the Indian coastal zones.

A rise in sea level has significant implications on the coastal population and agricultural performance of India. A variety of impacts are expected which include:

- Land loss and population displacement.
- Increased flooding of low-lying coastal areas.
- Agricultural impacts (like, loss of yield and employment) resulting from inundation, salinization, and land loss.
- Impacts on coastal aquaculture.
- Impacts on coastal tourism, particularly the erosion of sandy beaches.

The extent of vulnerability, however, depends not just on the physical exposure to sea-level rise and population affected, but also on the extent of economic activity of the areas and capacity to cope with impacts. The coastal ecosystems sustain a higher density of human population. The pressure on coastal areas has been growing due to migration from inland to the coastal zone making it vulnerable to the increased frequency and intensity of natural and human interventions. The reason for this increased pressure is due to the greater employment opportunities, when compared to inland areas of the coastal states, as some of the major urban centres are located in this region. For instance, three of the four major Indian metropolitan areas are located in the coastal region (Mumbai, Kolkata and Chennai). Moreover, out of the 35 urban agglomerations (UA) with a million plus population identified for India in the census of 2001, 18 (*viz.*, Rajkot, Ahmedabad, Vadodara, Surat, Greater Mumbai, Pune, Nagpur, Nashik, Bangalore, Kochi, Hyderabad, Vishakhapatnam, Vijayawada, Chennai, Coimbatore, Madurai, Asansol, and Kolkata) are situated in the coastal states. From among these, eight lie on the coastline. The activities in many of these areas tend to exceed the capacity of the natural coastal ecosystem to absorb them, making these regions vulnerable to the increased frequency and intensity of natural and man-made hazards.

Methods and Models for Assessing Vulnerability

Vulnerability is considered as a composite of: (a) climate-related *hazards* that are relevant and significant in the coastal zone; (b) *exposure*—socio-economic components, including human and manufactured capital, as well as natural ecosystems that are exposed to climate risk; (c) *adaptive capacity*—the ability of the exposed units to perceive and formulate a response and implement to climate risk, with a view to reducing impacts.

Assessment of coastal zones to projected climate impacts and development of adaptation strategies include:

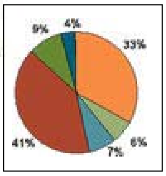
- a description and analysis of present vulnerability, including representative vulnerable groups (for instance, specific livelihoods at the risk of climatic hazards).
- descriptions of potential vulnerabilities in the future, including an analysis of pathways that relate the present to the future.
- comparison of vulnerability under different socio-economic conditions, climatic changes and adaptive responses.
- identification of points and options for intervention, which would lead to formulation of adaptation responses.
- relating the range of outputs to stakeholder decision making, public awareness and further assessments.

Greater emphasis is placed on the first two components, that is, hazard and exposure, and their combination, which are the actual climate impacts in coastal regions. While adaptive capacity is important, and key in determining *future*, as opposed to *current* vulnerability, there are a number of significant methodological and conceptual issues with regard to adaptive capacity.

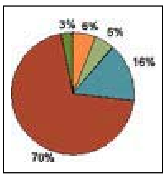
Climate-Related Coastal Hazards–Current Vulnerability

The characteristics of the key climate-related risks in the coastal zone, including sea-level rise and tropical cyclones and, are presented.

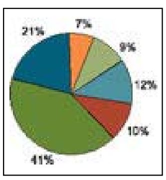
Table 3.8: Percent area for erosion and depositional segments of the coastline of the states along the West Coast of India (left panel) and East Coast of India (right panel).



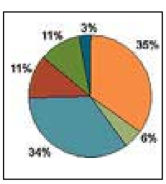
Gujarat has 'submerging type' of coastline, which is more prone to the effects of sea-level rise. The Gulf of Kutchh has a highly dynamic coastline. The Gulf of Khambhat is a potential site for shoal migration and vulnerable to large shoreline changes because of the prevalent macro-tidal regime. The southern coast of Gujarat has a highly dynamic coastline with erosion tendency.



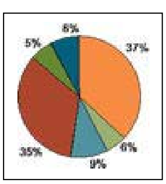
The northern coast of Maharashtra has an indented coastline with many creeks, inland waters, and pocket beaches. The coastline, though mostly rocky along the coast due to the presence of the Sahyadri Range, is under threat at many locations due to the reduced fluvial input. The west coast fault (a N-S trending regional tectonic feature) and the submergence characteristics add to the vulnerability of these regions.



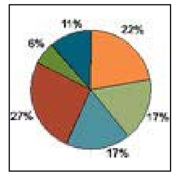
Goa has many pocket beaches. Owing to pressure from tourism-related anthropogenic activities, some of the beaches are destabilized and are vulnerable in the event of sea-level rise.



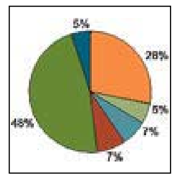
The shoreline of Karnataka is indented with hills, creeks, and small estuarine rivers, the mouths of which have dynamic shoaling. In the southern region, the shoreline is more dynamic compared to the north. The mouths of the small coastal rivers and backwaters at many places are undergoing erosion. The coastline at locations with dynamic and migrating shoaling activities is prone to destruction.



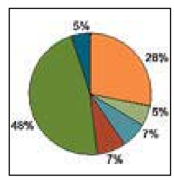
The shoreline of Kerala is, by and large, dynamic, with a high erosion tendency. The entire coastline of Kerala is vulnerable to sea-level rise, and needs special attention.



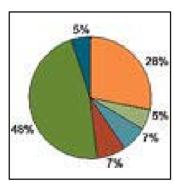
Pockets of high erosion all along the coast with high erosion in the Gulf of Mannar and the Tuticorin area. The southern part of Tamil Nadu is vulnerable due to localized segments of unstable shoreline.



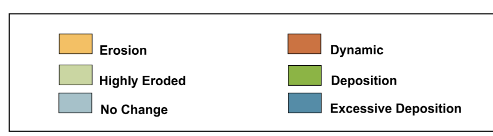
In Orissa the shoreline is dynamic due to the high fluvial input and is metastable in the creeks and backwaters. It is subjected to severe erosion during cyclones/depressions. The coastal area has numerous small and large rivers and their distributaries, which fan out into the coastal region, and are prone to salinity ingress, particularly in the event of sea-level rise.



The southern coast of Andhra Pradesh is more dynamic than the northern coast. The coasts along the mouths of all major rivers are highly dynamic, as the mouths of many perennial rivers are migratory. The area is also frequently affected by cyclones, and the shoreline is highly sensitive to such extreme natural processes



The fluvial flux from the Ganga and the Brahmaputra Rivers make the shoreline of West Bengal very dynamic due to the large. At many places, the shoreline is erosional (Digha Beach), and large changes in the island geomorphology have been observed. The delta region is also highly dynamic and the islands located in this region need special consideration. The Sunderban area and the Hooghly estuarine regions are the two other areas that are found to be the most vulnerable to the observed sea-level rise.

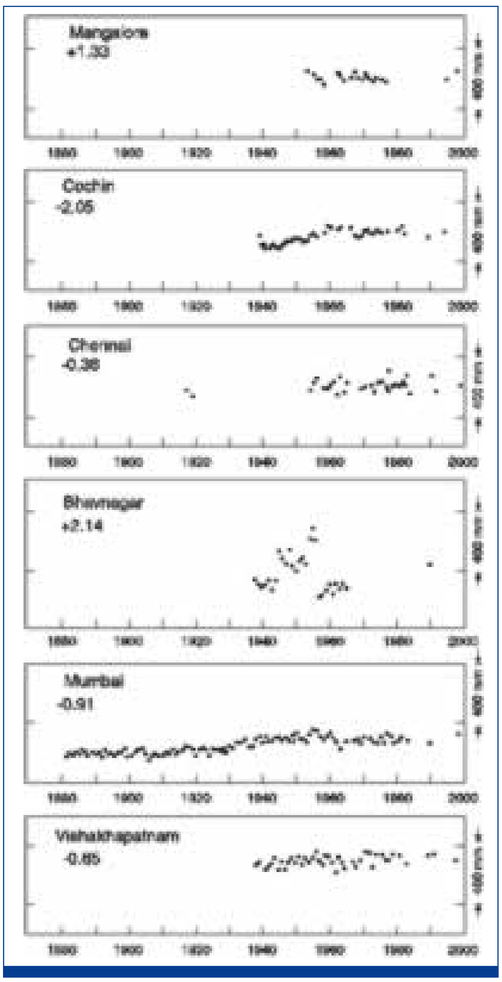


Sea-level Rise

This is based on available data shoreline changes over a short span of 10-15 years, along the Indian coastline. Using the available models, global sea-level rise of 10-25 cm per 100 years has been predicted due to the emission of GHGs. To separate the influences due to the global climatic changes the available mean sea-level historical data from 1920 to 1999 at 10 locations were evaluated. There is a large contrast in the observed sea level changes. The sea level rise along the Gulf of Kutchh and the coast of West Bengal is the highest. Along the Karnataka coast, however, there is a relative decrease in the sea level.

Shoreline morphologies respond to prevalent hydrography and the changes in the shoreline have been estimated and categorized broadly as erosive, dynamic, and depositional. Based on the comparisons of satellite data and hydrographic charts, the shoreline changes along the Indian coastline were examined for a 10-15 year span. The state-wise characteristics of the shoreline for the Indian coast are shown in Tables 3.8.

Figure 3.32: Estimated sea level rise at selected locations along the Indian Coastline.*



*The values on the left-side corner indicate sea-level variations per year. A minus figure indicates a relative increase in the mean sea level with respect to the land.

The magnitude of tides has been predicted for 121 stations and has a high correlation with observed tides. The most vulnerable areas of the Indian coastline, determined from the risk assessment, is identified from the integration of physiographic evaluation, site-specific sea-level changes, tidal environment and hydrography data. The physiographic settings and tidal regime are important parameters to determine the resilience of an area to the influence of sea-level rise. From the estimated tidal environment at 121 stations, it is observed that the mean spring tide ranges show a progressive increase towards north along the east coast (Figure 3.32). A similar trend is also observed along the West Coast. Some of the highest tidal ranges are measured at stations in the Gulf of Kutchh and in the Gulf of Khambhat. From the time series mean spring tide amplitude, it is deduced that the northern areas along the east, as well as west coasts have a higher tidal range and very wide intertidal and supratidal zone.

The areas along the Indian coastline that are likely to be vulnerable to the predicted sea-level rise based on predicted sea level changes, tectonics, prevalent hydrography, and physiography of the areas can be seen from the Figure 3.33. These vulnerable regions need special attention.

Tropical Cyclones

For the Indian region, the data on cyclonic events is available from 1877. The spatial, temporal patters of occurrence is presented in Box 3.8.

Figure 3.33: Likely vulnerable locations due to sea level rise.

Box 3.8: Cyclonic Events

The Spatial Pattern of Cyclone Incidences and the Facts (data from 1877 to 1990)

- 1,474 cyclones originated in the Bay of Bengal and the Arabian Sea during this period.
- 964 cyclones crossed the Indian coastline.
- Three districts of West Bengal (174 events).
- Seven districts of Orissa (422 events).
- Nine districts of Andhra Pradesh (203 events).
- 15 districts of Tamil Nadu (100 events)

The Temporal Pattern of Cyclone Incidences

- Depressions have a distinct peak in the month of August.
- Storms have two distinct peaks in June and October.
- Severe storms have distinct peaks in May and November.
- The total number of tropical cyclones seasonality follow the path of the depression.

Average based on the Facts:

- 8.45 cyclones cross the Indian coastline per year.
- 5.15 depressions cross the Indian coastline on an average per year.
- 1.93 storms occur on an average per year.
- 1.35 severe storms occur on an average per year.

Trends in Tropical Cyclone Incidence: Storms depict a decreasing trend (-0.017/year) significant at one per cent level. Severe Storms (SS) show an increasing trend (0.011/year) significant at one per cent level. Cyclone incidences show mixed trends spatially. West Bengal and Gujarat showed significant increasing trend, while Orissa showed a significant decreasing trend.

***Cyclone Hazard Indices*:** Indices were developed to represent the cyclone hazard and to identify the coastal districts that face the maximum cyclone occurrences. Three indices were computed. The first index is the frequency of events (by cyclone type, i.e., depressions, storms and severe storms) in a particular district. The second is by normalizing the number of events in a district by the coastline length of the districts; and the third is normalizing the number of events in a district by area of that coastal district. Table 3.9 presents the top 10 districts according to each of the indices for the severe storm category of cyclones.

The indices have been developed for the districts, rather than a continuous and a uniform metric like per 100 km of coastline length, since the impact data is reported for districts. Hence, there are differences in rankings for districts on the basis of different indices. Thus, Chennai ranks first when the number of cyclones is normalized by district area and Karikal ranks first when the number of cyclones is normalized by district coastline length, whereas South 24 Parganas ranks first for other indices. This is because Chennai and Karaikal have much smaller area and coastline length respectively, when compared to other districts.

Table 3.9: Ranking of the districts based on different indices of cyclone hazard

Indices / Rank	Frequency of SS	SS normalized by coastline length	SS normalized by district area
1	South 24 Parganas (WB)	Karaikal (Pondicherry)	Chennai (TN)
2	North 24 Parganas (WB)	Nagapattinam (TN)	Nagapattinam (TN)
3	Nellore (AP)	Villupuram (TN)	North 24 Parganas (WB)
4	Srikakulam (AP)	Chennai (AP)	Jagatsinghpur (Orissa)
5	Nagapattinam (TN)	Jagatsinghpur (Orissa)	Kendrapara (Orissa)
6	Junagadh (Gujarat)	Pondicherry	Baleshwar (Orissa)
7	East Godavari (AP)	Cuddalore (Orissa)	Srikakulam (AP)
8	Baleshwar (Orissa)	North 24 Parganas (WB)	South 24 Parganas (WB)
9	Kendrapara (Orissa)	Nellore (AP)	Porbandar (Gujarat)
10	Krishna (AP)	Baleshwar (Orissa)	Bhadrak (Orissa)

Exposure indices: Exposure refers to the extent to which the human systems are unprotected from climate-related natural hazards. Exposure can be understood of in two ways–physical and socio-economic. Historical record that spans three decades (census publications for the 1971, 1981, 1991 and 2001 census years) have been used to study the aspects of the population and construction of households at the coastal district level. Exposure indicators based on ***Housing Index*** (using the distribution of housing stock across the different categories of houses (based on the wall material) and the knowledge of susceptibility of a particular category of house to storm and flood damage); and ***Population index*** (the density of population has been considered the measure of population exposure to hazards).

Based on the rankings of 52 coastal districts belonging to eight states:

- The top five districts which had the maximum exposure in terms of housing were
  - Valsad, Uttar Kannada, Ratnagiri, Ganjam and Kozikhode. Of these:
  - four lie on the west coast (cyclone incidence is lesser on the west coast when compared to the east coast).
  - This implies vulnerability of west coast (submergent type) to sea level rise.
- The top five districts with high exposure levels considering exposure in terms of density of population were:
  - South 24 Parganas, industrialized towns like Surat, place of tourist attraction Sindhudurg and towns in river floodplains and deltas West and East Godavari Krishna.
  - Greater Bombay and Chennai have the highest exposure levels (urban).
- The exposure levels have increased over the years in terms of the absolute number of people, density of population and the size of the housing stock.

Data on human mortality, livestock mortality, damage to houses, damage to crop area, loss in monetary terms and population affected are used to measure impacts of climate-related extreme events. The approach followed for analyzing the impacts of the cyclones has been to rank the districts on the basis of an impact index, in order to obtain an idea about the districts that have historically suffered the maximum impacts.

The top five districts in the east coast, namely, Nagapattinam, Jagatsinghpur, Balasore, Bhadrak and Nellore and Porbandar and Junagadh, ranked the highest in terms of mortality due to the severe storms which occurred in the period 1971 to 1990.

Current Vulnerability of the Indian Coastal Zones: For assessing the vulnerability of the Indian coastal zones, three indices each for hazard, exposure and impacts were selected and computed. The impacts were represented by cumulative deaths, deaths per event and cumulative deaths per million of the population. Statistical correlations (Spearman's rank) between different indices were computed. The district ranks for the impact indices and hazard indices are correlated with each other. However, the district ranks for the exposure indices are not correlated, implying that the hazard, exposure and impacts interact in complex ways to define the vulnerability of a district. To capture this, a complex cluster analysis was performed. The cluster analysis grouped the 14 districts used in the analysis into two major clusters, classified as highly vulnerable and somewhat vulnerable. The rest were classified into less vulnerable cluster. Table 3.10 shows the classification of Indian coastal districts on the basis of vulnerability.

Agricultural Development in Coastal Districts: The eastern coast districts are major producers of rice in India, and adverse effects of climate change may have an impact on production and availability of food grains in the country. The literature shows that these shortfalls have the potential to create market imbalances that can further lead to market and price fluctuations. Agricultural production in these coastal areas is heavily dependent on climatic conditions, despite the availability of irrigation facilities. In Tamil Nadu, the growth rate for the area irrigated is declining. In other states, a rise in area irrigated has given a thrust towards commercial crops, such as groundnut and sugarcane and, hence, extreme climatic shocks like storms and severe storms can have a negative effect on agriculture and the incomes of people. The settlements in coastal areas of India have a high percentage of people, whose income is derived from climate-sensitive sectors like agriculture, fisheries and forestry.

Table 3.10: Classification of Indian coastal districts on the vulnerability to cyclones

Vulnerability	Districts
Highly vulnerable	Cuttack (now Jagatsinghpur and Kendrapara) in Orissa; Nellore in Andhra Pradesh; Thanjavur (now Nagapattinam) in Tamil Nadu; Junagadh (now Junagadh and Porbandar) in Gujarat.
Somewhat vulnerable	North 24 Parganas in West Bengal; South 24 Parganas in West Bengal; Baleshwar (now Baleshwar and Bhadrak) in Orissa; Srikakulam in Andhra Pradesh; East Godavari in Andhra Pradesh; Guntur in Andhra Pradesh; Krishna in Andhra Pradesh; Chengalpattu (now Thiruvallur) in Tamil Nadu; South Arcot (now Cuddalore) in Tamil Nadu; and Ramnathpuram in Tamil Nadu.
Less vulnerable	The rest of the coastal districts.

Climate-related Coastal Hazards—Future Scenario

The past observations on the mean sea level along the Indian coast show a long-term rising trend of about 1.0 mm/year. However, the recent data suggests a rising trend of 2.5 mm/year in the sea-level along Indian coastline. Model simulation studies, based on an ensemble of four AOGCM outputs, indicate that the oceanic region adjoining the Indian subcontinent is likely to warm at its surface by about 1.5-2.0^{o}C by the middle of this century and by about 2.5-3.5^{o}C by the end of the century. The corresponding thermal expansion, related sea-level rise is expected to be between 15 cm and 38 cm by the middle of this century and between 46 cm and 59 cm by the end of the century. A one-metre sea level rise is projected to displace approximately 7.1 million people in India, and about 5,764 km^2 of land area will be lost, along with 4,200 km of roads. An increase in the frequency of severe cyclonic storms is likely under the climate change scenario; this may enhance the vulnerability of those districts that are already ranked as vulnerable under the current climate scenario.

Adaptation Options

There are a number of adaptation options that could be adopted for reducing the vulnerability of a coastal system to climate-related hazards. These adaptation options could be classified into structural and non-structural interventions. Structural interventions basically attempt to change the physical conditions of the natural system and resource base through technological interventions. It involves putting up of artificial physical structures in the landscape, for example building dikes or seawalls or enhancing the natural setting or landscape in such a manner so as to provide protection from the climate-related coastal hazards. Planting of mangroves, beach nourishment, etc., are some examples of other interventions. Non-structural approaches employ land-use controls, information dissemination, and economic incentives to reduce or prevent disasters. The Coastal Regulation Zone, or using insurance to cover the risk related to impacts of climate-related hazards would fall under the non-structural measures. A coastal zone management plan should also include research and development activities for cost-effective methods for the protection of coastal lands. Rules and regulations must be framed and enforced to have a control over the developmental activities and to put restrictions on seaward extrusion.

CLIMATE CHANGE IMPACTS ON HEALTH

People have adapted to living in a wide variety of climates around the world—from the tropics to the arctic. Both climate and weather have a powerful impact on human life and health. Human physiology can handle most variations in weather, within certain limits. Certain health outcomes associated with the prevailing environmental conditions include illnesses and death associated with temperature extremes, storms and other heavy precipitation events, air pollution, water contamination, and diseases carried by mosquitoes, ticks, and rodents. As a result of the potential consequences of these stresses acting individually or in combination, it is possible that

Coastal areas and livelihoods at risk.

projected climate change will have measurable beneficial and adverse impacts on health.

In India, the overall susceptibility of the population to environmental health concerns has dropped dramatically during the past few years with the improvement in availability of the health infrastructure. However, the extent of access to and utilization of health care has varied substantially between states, districts and different segments of society; to a large extent this is responsible for substantial differences between states in health indices of the population. During the 1990s, the mortality rates reached a plateau and the country entered an era of dual disease burden. Communicable diseases have become more difficult to combat because of the emergence of insecticide-resistant strains of vectors and antibiotic-resistant strains of bacteria. Under-nutrition, micro-nutrient deficiencies and associated health problems coexist with obesity and non-communicable diseases in the country. The existing system suffers from inequitable distribution of institutions and access to nutrition and health care.

Current climate trends have shown an increase in maximum temperatures, heavy intense rainfall in some areas and emergence of intense cyclones. In the summer of 1994, western India experienced temperatures as high as 50°C, providing favourable conditions for disease-carrying vectors to breed. In 1994, as summer gave way to the monsoon and western India was flooded with rains for three months, the western state of Gujarat was hit by a malaria epidemic. Weather conditions determine malaria transmission to a considerable extent. Heavy rainfall results in puddles, which provide good breeding conditions for mosquitoes. In arid areas of western Rajasthan and Gujarat, malaria epidemics have often followed excessive rainfall. In very humid climates, drought may also turn rivers into puddles. Similarly, the super-cyclone in 1999 caused at least 10,000 deaths in Orissa and the total number of people affected was estimated at 10-15 million.

Changes in climate may alter the distribution of important vector species (for example, mosquitoes) and may increase the spread of disease to new areas that lack a strong public health infrastructure. High altitude populations that fall outside areas of stable endemic malaria transmission may be particularly vulnerable to increases in malaria, due to climate warming. The seasonal transmission and distribution of many other diseases transmitted by mosquitoes (dengue, yellow fever) and by ticks (Lyme disease, tick-borne encephalitis), may also be affected by climate change. Some of the key health impacts that might arise due to climate change are listed in Table 3.11.

Projections of the extent and direction of potential impacts of climate variability and change on health are extremely difficult to make with confidence because of the many confounding and poorly understood factors associated with potential health outcomes. These factors include the sensitivity of human health to elements of weather and climate, differing vulnerability of various demographic and geographic segments of the population, the movement of disease vectors, and how effectively prospective problems can be dealt with. In addition to uncertainties about health outcomes, it is very difficult to anticipate what future adaptive measures (for example, vaccines and the improved use of weather forecasting to further reduce exposure to severe conditions) might be taken to reduce the risks of adverse health outcomes. Therefore, in this scenario, carrying out improvements in environmental practices, preparing disaster management plans and improving the public health infrastructure in India, including disease surveillance and emergency response capabilities, will go a long way in coping with the impacts of climate change on human health.

Table 3.11: Known effects of weather/climate and potential health vulnerabilities due to climate change.

Health Concerns	Vulnerabilities due to climate change
Temperature-related morbidity	Heat- and cold-related illnesses.
	Cardiovascular illnesses.
Vector-borne diseases	Changed patterns of diseases.
	Malaria, filaria, kala-azar, Japanese encephalitis, and dengue caused by bacteria, viruses and other pathogens carried by mosquitoes, ticks, and other vectors.
Health effects of extreme weather	Diarrhea, cholera and poisoning caused by biological and chemical contaminants in the water (even today about 70% of the epidemic emergencies in India are water-borne).
	Damaged public health infrastructure due to cyclones/floods.
	Injuries and illnesses.
	Social and mental health stress due to disasters and displacement.
Health effects due to insecurity in food production	Malnutrition and hunger, especially in children.

Malaria is one of the important climate-change related diseases that has been extensively studied since the early 1960s in India. Records of incidences and mortality due to the same are inadequate. Malaria was chosen for an in-depth study to develop the relationship between climate parameters and disease incidence, and for studying its future spread in the climate change context.

The Present Scenario of Malaria

Malaria is caused by a species of parasites belonging to the genus *Plasmodium*. There are four species of the malaria parasite namely, *Plasmodium vivax* (or *P. vivax*), which is extensively spread geographically, and is present in many temperature zones, as well as the tropics and sub tropics, *P. falciparum* is the most common species in tropical areas and the most dangerous clinically, *P. ovale* resembles vivax and replaces it in West Africa and *P. malariae* is much less apparent, with low parasitaemia and is found mainly in tropical Africa.

Malaria is endemic in all parts of India, except at elevations above 1,800 metres and in some coastal areas. The principal malaria-prone areas are Orissa, Madhya Pradesh, Chhattisgarh, and the north-eastern parts of the country. Periodic epidemics of malaria occur every five to seven years. According to the World Bank, in 1998 about 577,000 Disability-Adjusted Life Years (DALYs) were lost due to malaria. The principal malaria vectors are mosquitoes of the genus *Anopheles*. These include *A. culicifacies* (a rural vector), in most parts, *A. stephensi* (an urban vector) and *A. fluviatilis, A. minimus, A. dirus* and *A. sundaicus* in other parts of India.

Amongst these states, Orissa has the highest Annual Parasite Index (API) which is greater than 10, followed by Madhya Pradesh and Chhattisgarh (API between 6-10). The occurrence is high in Jharkhand, which is mainly inhabited by a tribal population (Figure 3.34). Here, the incidence increased from 35,000 to more than 40,000 between 1995 and 2000.

In the early 1950s, malaria was not only the cause of morbidity and mortality, but also one of the major constraints in ongoing developmental efforts. The National Malaria Control Programme was spectacular successful initially in bringing down the incidence of malaria from 75 million cases with 0.8 million deaths, to 0.1 million cases with few deaths by 1965, even though there was no well-established health care infrastructure in the rural areas. Subsequently, however, there was a resurgence of malaria. In 1976, over 6.7 million cases were reported (Figure 3.35). From 1977, the National Malaria Eradication Programme (NMEP) began implementing a modified plan of operation for the control of malaria. Despite these efforts, the number of reported cases of malaria has remained around two million in the 1990s.

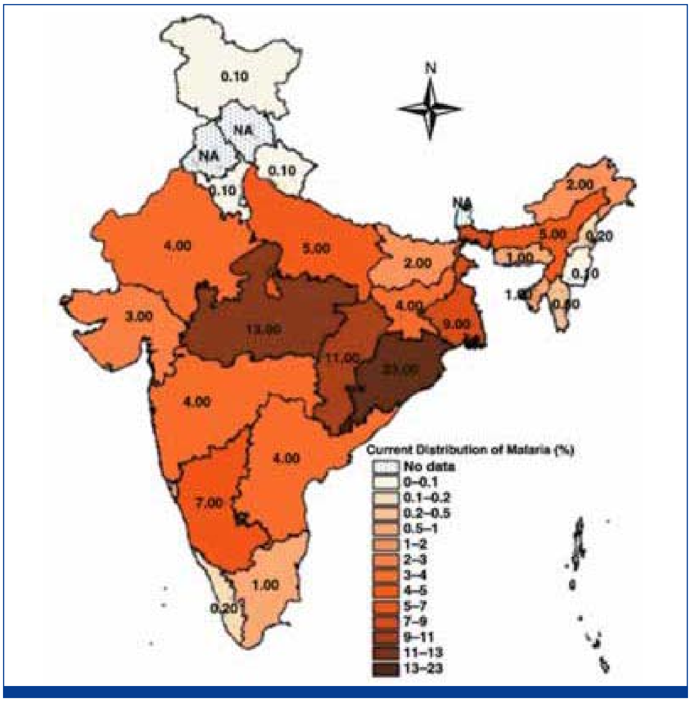


Figure 3.34: Distribution of malaria in India in 2001.
Source: National Malaria Eradication Programme, 2002.

Figure 3.35: The malaria situation in India between 1976 and 2001.
Source: Ministry of Health and Family Welfare, 2003.

The increase in malaria incidences are attributed to the resistance of mosquitoes to pesticides, and the resistance of parasites to anti-malarial drugs, thus, limiting the effectiveness of malaria control attempts through the NMEP. The sudden jump in the number of deaths to 1100 in 1993 corresponding to the same number of incidences in the previous years may be explained by the improved reporting of the health workers of NMEP (now known as National Anti-Malaria Programme or NAMP).

Factors influencing malaria

Climate Parameters: For most vectors of malaria, the temperature range 20°C-30°C is optimal for development and transmission. Relative humidity higher than 55 per cent is optimal for vector longevity, enabling the successful completion of sporogony. Malaria transmission requires a minimum average temperature higher than 15°C for *P. vivax* and 19°C for *P. falciparum*, and this temperature should sustain over a period of time for the completion of sporogony. For example, when average temperature, humidity, precipitation and incidences have been plotted for Gujarat (Figure 3.36), the maximum incidences are seen to occur in the months of June, July and August when relative humidity is highest i.e., greater than 60 per cent and less than 80 per cent, at temperatures ranging between 25°C to 30°C. This window shifts from state to state as we go from south to north, depending on the arrival of the monsoon. Hence, to represent this diversity, climate determinants are further classified into Class I, II and III cases, which are needed for the growth and effective transmission of malaria vectors (Table 3.12).

Table 3.12: Climate determinants for *P. vivax* development and transmission.

Type	Temperature range (°C)	Humidity (%)	No. of days to develop
Class I	15–20	>60% & <80%	20±5
Class II	20–25	>60% & <80%	15±5
Class III	25–30	>60% & <80%	8±5

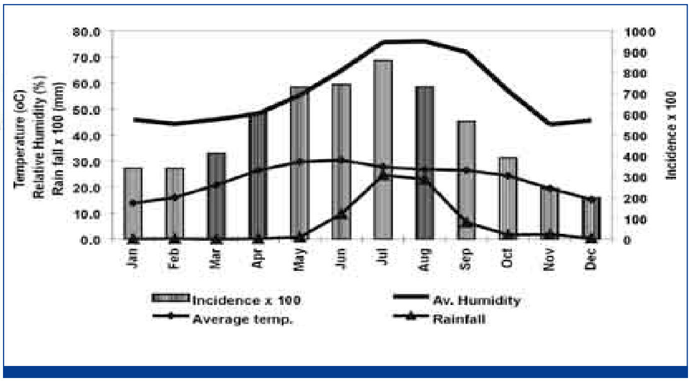


Figure 3.36: Dependence of malaria incidence on climate determinants.

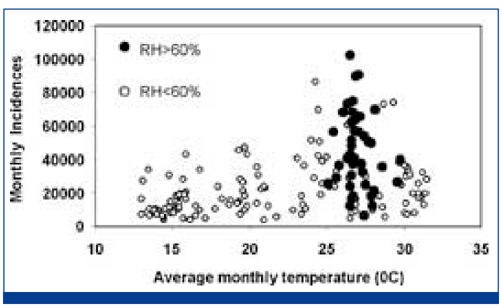


Figure 3.37: Variation of malaria incidences with temperature for relative humidity greater than and less than 60%.

These classifications are based on extensive climate data analysis at a daily level.

A analysis of temperature versus incidences for each state, for the days when humidity was less than 60 per cent and between 60 per cent to 80 per cent indicated that Class I conditions prevail in the northern regions of India and Class II and Class III conditions prevail in the southern states. For example, in Gujarat, the temperature window corresponded to 26°C -32°C (Figure 3.37), with peak incidence at 27°C, which correspond to Class III conditions. However, as regards the relative influence of temperature and precipitation for relative humidity greater than 60 per cent, it is observed that temperature has more influence over malaria transmission than does precipitation (Figure 3.38). Since the correlations are not strong (i.e. greater than 0.95), other non-climate parameters such as socio-economic conditions also influence vector generation and malaria transmission. Further in-depth data analysis for other states is required at the district level to conclusively establish the dominance of temperature with respect to precipitation on incidence for a given humidity condition. Other than temperature, precipitation and humidity controlling malaria at the local level, the link with global climate has also been observed in generating malaria in some years in India. (Box 3.9).

Urban settlements: Increasing urban population creates a large number of peri-urban areas on the outer limits of cities, which now account for 25-40 per cent of the Indian population. These areas are unplanned and poor people live here in unsanitary conditions. A suitable environment is thuscreated for epidemics to be caused by increases in *A. culicifacies* (which breeds in clean water on the ground due to rain) and *A. stephensi* (which breeds in wells and stored water). *A. stephensi* has extended its distribution in India over the past four decades by entering more towns and peri-urban areas. This spread in *A. stephensi* is related to the spread of piped water systems throughout the

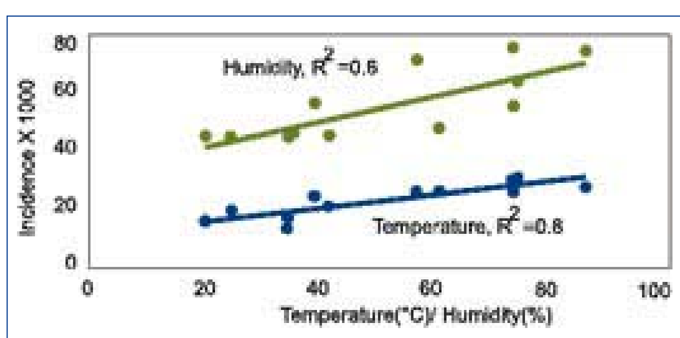


Figure 3.38: Relative importance of temperature and humidity in malaria incidence.

Box 3.9: The Influence of *El Niño* Southern Oscillation (ENSO) events

An increased risk of malaria and excessive rainfall can be expected in the years following the onset of La Nina and the opposite during *El Niño* events. Most of the *El Niño*/La Nina years in India have resulted in below or above normal incidences of malaria, respectively. Although there is a general tendency for the malaria incidences to be below or above normal during drought/flood monsoon seasonal rainfall years, the separation is not as good as that observed in the case of *El Niño*/La Nina events.

Malaria incidences during 1961–1995.

El Niño years	Incidence	La Nina Years	Incidence	Excess years	Incidence	Deficit years	Incidence
1965	–5327	1964	8740	1970	–3102	1965	–5327
1969	10503	1966	13455	1975	252329	1966	13455
1972	–6506	1970	–3102	1983	49907	1968	30730
1976	24462	1973	122977	**1988**	**66833**	1972	–6506
1982	–38534	1975	252329	1994	137745	1974	211768
1987	**–19702**	1978	87133			1979	9856
1991	166370	1983	49907			1982	–38534
1992	–42242	**1988**	**66833**			1985	–110449
						1986	93271
Drought/flood years						**1987**	**–19702**

country. Peri-urban malaria is a new malaria phenomenon, because migrants often have chronic malaria and the poor environmental conditions in their temporary settlements foster mosquito breeding and malaria transmission.

Poverty : Malaria is declining in states of India that have performed well in economic terms over the last decade and has increased where the performance is below average. The ever-increasing population, widespread poverty and illiteracy, malnutrition and anaemia and the low socio-economic status creates an immense pressure on the environment, and provision of safe drinking water and basic sanitation for millions. Poverty is multidimensional. It deprives the poor from access to the basic health benefits.

Irrigation: Irrigated area has increased in India from 26.8 Mha in 1950 to more than 90 Mha in 1995. It was introduced in some areas for increasing agricultural productivity by building a large number of dams and canals. The seepage from canals and a rise in the water tables create a source of still water for malaria breeding. Examples of such regions can be found in the Thar desert, where mismanagement of the widespread developmental activities of canal-based irrigation have led to malaria becoming endemic. No malaria incidences were recorded here earlier. In Uttar Pradesh. *A. culicifacies* which is resistant to DDT and HCH pesticides took over from *A. fluviatilis*, when irrigation was implemented in the state. Also, the Sardar Sarovar dam, an irrigation project on the Narmada river, though not fully implemented yet, has already lead to the invasion of *A. culicifacies* and *A. fluviatilis*, extending the malaria season, changing the area into an endemic malaria region and causing a 10-15 fold increase in malaria.

Agricultural practices: Agricultural practices, such as rice farming, create large areas of stagnant water that are suitable breeding grounds for malaria vectors. Rice fields in India provide breeding habitats for 20 *Anopheles* species. However, there are differing opinions about whether increases in area under rice cultivation correlate with increases in malaria.

Land-use change: Forests, where a majority of the tribal population resides, are a reservoir of high levels of malaria in India. Currently, malaria in the forests accounts for 30 per cent of all malaria in the country and it is stable with high transmission rates. Most incidences in these areas are caused by *P. falciparum*, which is increasingly becoming more resistant to chloroquin and, in certain locations, to other anti-malarial drugs. Deforestation, mainly carried out for development projects and due to economic pressures, allows new vectors to invade the forest fringes, producing epidemics, especially in the non-tribal non-immune people who move to these areas for jobs. Some forest areas in India also experience moderate levels of chloroquin resistant *P. falciparum.*

Malaria scenario under climate change

Presently, the transmission window (based on minimum required conditions for ensuing malaria transmission) is open for 12 months in eight states (Andhra Pradesh, Chhattisgarh, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu and West Bengal), nine to 11 months in the north-eastern states (Gujarat, Haryana, Madhya Pradesh, Punjab, Rajasthan, Uttar Pradesh and Uttaranchal). The states of Himachal Pradesh and Jammu and Kashmir have transmission windows open for five to seven months, respectively. When the temperature and relative humidity are considered together for determining the transmission window, it is observed that for less than 60 per cent relative humidity, the transmission window is reduced by one to five months. For example, in Madhya Pradesh, the transmission window is open only for four months if both temperature and relative humidity are considered, while it is open for eight months if only temperature is considered. Therefore, it appears that transmission may take place at less than 60 per cent relative humidity.

Considering a 3.8°C increase in temperature and a seven per cent increase in relative humidity by the 2050s (with reference to the present), nine states of India may have transmission windows open for all 12 months. The transmission windows in the states of Jammu and Kashmir and Rajasthan may increase by three to five months as compared to the base year. States like Orissa and some southern states, where the mean temperature is more than 32°C in four to five months, a further increase in temperature is likely to cut the transmission window by two to three months (Figure 3.39). Since there exists climate as well as geographical diversity within a state, district-wise projections are desirable.

The above approach is a preliminary attempt to project

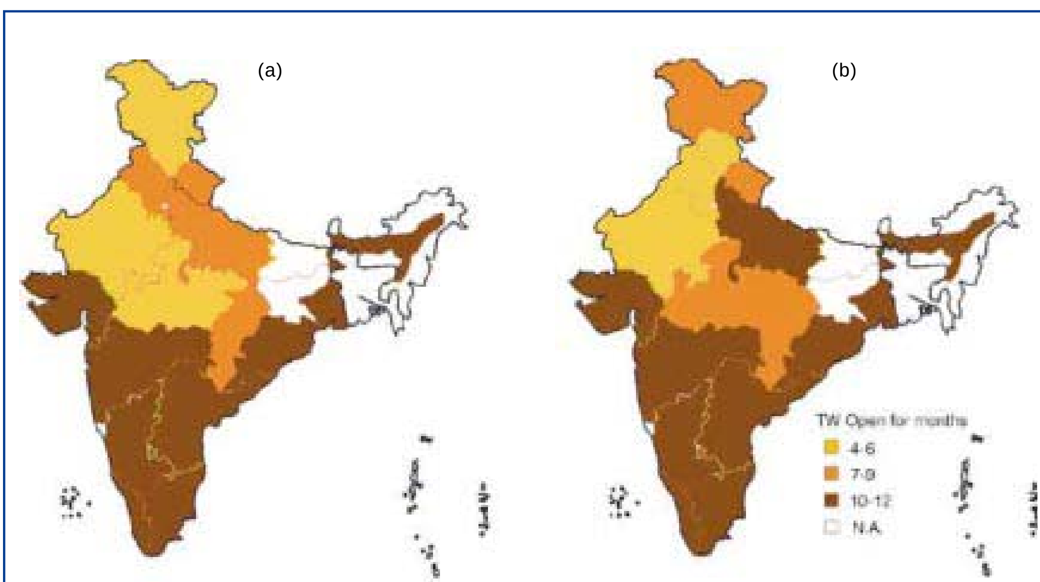


Figure 3.39: Transmission window of malaria in different states of India: (a) for base case (year 2000); and (b) under projected climate change scenario (2050s).

climate change impacts. An integrated approach is required to evaluate the impacts of climate change on malaria in India, that will include not only the future climate and land-use pattern parameters but also would integrate the projected socio-economics which need to include access to medical intervention in the region/state/district. This is further corroborated by the fact that in the northern Indian states, the winter months are usually not suitable for transmission of malaria but some cases do occur through all the months. It may be due to relapsed cases, which is a common phenomenon in *P. vivax* parasite. Therefore, the projections of malaria in 2080 based on present projections of temperature and relative humidity, may not be accurate.

Adaptation Strategies

The Government of India since the late 1940s has been implementing various programmes to control malaria in the country. Initially, as a result of these programmes, the disease subsided in the 1960s, but since the late 1970s it has become resistant to the interventions. These measures will also be relevant as potential adaptation strategies in the climate change regime. Indeed, improved malaria drugs, potential immunization and enhanced economic welfare of the people may reduce the incidence of malaria.

Existing Government policies

India started using the pesticide DDT to control malaria beginning in 1946 (see Box 3.10). In 1953, when 70 million cases and 0.8 million deaths occurred due to malaria (NMEP, 1996), the National Malaria Control Programme was started. This programme was renamed the National Malaria Eradication Program (NMEP) in 1958 due to the success of DDT and the commitment to malaria eradication in India at that time. It was believed that it could eradicate malaria in seven to nine years, but the disease began to re-emerge in 1965. After 1965, malaria rates in India rose gradually and consistently, with a peak of 6.47 million cases in 1976 (NMEP, 1996). This resurgence of malaria caused India to begin an attempt to control rather than eradicate malaria in 1977 with a Modified Plan of Operation (MPO), which also comprised the *P. falciparum* Containment Programme (P_f CP). The P_f CP aimed to contain the spread of falciparum malaria, which is the most commonly resistant and deadly strain of malaria. During MPO, chloroquin distribution was extended through Fever Treatment Deport and Drug Distribution Centres, in addition to other means through which malaria drugs had already been distributed. MPO also only used residual insecticides in areas with an API index greater than two. This method still relied mainly on spraying pesticides and distributing anti-malarial drugs, although there was also an attempt to get more local officials involved in anti-malarial activities and an increase in research. By 1985, it seemed as though the NMEP would succeed in controlling malaria, because there were only two million cases of malaria and the incidence rate had stabilized. India has, however, experienced more epidemics and deaths from malaria in the 1990s, along with the creation of a new malaria phenomenon. In 1994, there were large-scale epidemics of malaria throughout the country, and since then malaria mortality has increased.

Box 3.10: Malaria control in India

Year	Action
1946	India started using DDT
1953	NMCP is started
1958	NMCP becomes the NMEP
1959	The first-time vector resistance is detected in India (in Gujarat)
1965	Malaria begins to re-emerge
1976	The peak of malaria cases in the re-emergence period
1977	India starts MPO and P_f CP
1985	Only 2 million annual cases of malaria in India
1991	The peak of P. falciparum cases
1994	Large-scale epidemics, particularly in the Eastern and Western parts of India
1997	NMEP to NMAP (focus shifts from malaria eradication to malaria control)

According to the Planning Commission, despite extensive malaria eradication efforts, the number of reported cases of malaria has remained around two million in the 1990s. Financial assistance also has been received from the World Bank for the Enhanced Malaria Control Programme (EMCP) to cover a 100 predominantly *P. falciparum* malaria endemic tribal-dominated districts in Andhra Pradesh, Bihar, Jharkhand, Gujarat, Madhya Pradesh, Chhattisgarh, Maharashtra, Orissa and Rajasthan and 19 other cities. The project also has the flexibility to divert resources to any area in case of a malaria outbreak. In other areas, the NMAP continues to be implemented as a centrally sponsored scheme on a 50:50 cost-sharing basis between the centre and states in urban and rural areas. The central government provides drugs, insecticides and larvicides and also technical assistance/guidance as and when the state governments require. The state governments meet the operational cost, including salaries. In view of the high incidence of malaria (particularly of falciparum malaria) and high mortality, a 100% central assistance under the NAMP is being provided to the north-eastern states since 1994.

Although there has been an enhanced amount allocated for malaria eradication in the Ninth Plan, the decline in cases in this period was not commensurate with the substantial increase in funding. The rising proportion of *P. falciparum* malaria, increased vector resistance to insecticides and the growing parasite resistance to chloroquin, will render malaria containment and control more difficult in the Tenth Plan period. Since the Ninth Plan goal for reduction in API and morbidity has not been achieved, the Tenth Plan aims to achieve a morbidity and mortality rate reduction by 25 per cent in 2007 and 50 per cent in 2010 (Box 3.11).

Box 3.11: Goals of the Tenth Plan

Parameter	To achieve
Annual Blood Examination Rate (ABER)	Over 10%
API	1.3 or less
Moribidity and Mortality	Reduce by 25% by 2007 and 50% by 2010

Source: Tenth Five year plan, Planning Commission, Government of India, 2002.

Adaptation options in the climate change regime

It is essential that adaptation policies are designed in such a way that they take into account the uncertainties associated with the impacts of climate change, the specific anticipated changes in the existing disease conditions, including the expected improvement in the socio-economic conditions of the people in the future. Thus, in addition to disease specific measures, the following actions might be taken to develop adaptation strategies for the future:

- Improved surveillance and monitoring systems.
- Develop vector specific regional maps.
- Technological engineering strategies.
- Improved infrastructure to avoid artificial breeding.
- Medical interventions.
- Develop predictive models linking climate and incidence.
- Develop integrated environmental management plans.
- Public education.

A combination of these options can be used in addition to the ongoing efforts of the government to control malaria. The appropriateness of these measures will of course be decided by the local experts according to the health care needs of the public in the region and some of them may be temporary in their effectiveness.

Future Research Needs

The research results presented here, vis-a-vis the relationship between malaria and its determinants, and the likely spread of malaria to other regions are not conclusive by themselves. Since India has a diverse climate and socio-economic pockets, conditions conducive to malarial vector growth and its transmission vary at small spatial scales. Therefore, more research is required for a better assessment of malaria transmission under the additional climate change scenario. Further research needs to include:

- A study of the effect of different combinations of temperature and relative humidity on the development of malaria vectors infected with *P. vivax* and *P. falciparum*, the common parasites of malaria.
- A study of the impact of rainfall on creation of breeding habitats of malaria vectors/or flushing off the breeding habitats, in different malaria paradigms.
- District-wise prospective studies in different eco-

epidemiological types of epidemic prone areas to evaluate the role of temperature, rainfall and RH on mosquito vectors and malaria so as to develop an early warning system for proactive adaptation measures.

- For determining the transmission windows more definitively in the climate change scenario, an integrated assessment approach is required. This will link the outputs of the regional climate change models with the anticipated socio-economic trends, soil moisture, surface water run-off, vegetation cover, and the biogenic characteristics of malaria.

Key Findings

The transmission windows of opportunity conducive to malarial vector growth and transmission are unique to India and are defined in terms of climate parameters as Class I, Class II and Class III which correspond to different temperature ranges and durations when the humidity persists between 60 per cent to 80 per cent. This differs from state to state as the topography and land use have high variability. Temperature plays a greater role with respect to precipitation in the transmission of malaria.

Malaria has not yet penetrated elevations above 1,800 metres and some coastal areas. However, some of these areas may be penetrated by malaria in future due to climate change. It is projected that during the 2080s, 10 per cent more states may offer climatic opportunities for malaria vector breeding throughout the year with respect to the year 2000. These opportunities are projected to increase by three to five months in Jammu and Kashmir, and western Rajasthan, while they may reduce by two to three months in the southern states as temperatures increase.

The disease potential, i.e., the risk of contracting malaria by a population is the result of a combination of parameters such as climate change, public and private health capabilities, and man-made conditions conducive to malaria, such as unhygienic surroundings with accumulated water pools. Development associated with improved access to health systems, housing conditions, better infrastructure for waste disposal, better sanitary systems and new technological interventions vis-a-vis medication for malaria will play a key role in checking the spread of malaria in the future.

CLIMATE CHANGE IMPACTS ON ENERGY AND INFRASTRUCTURE

Infrastructure is an engine for economic development. It may be broadly defined as a system of linkages that facilitate and enable the flow of goods and services. These linkages include road, rail and airways; river systems, electric power systems, and all the different types of communication and service lines. It also includes the built and engineered entities, the factories, buildings, dams, and all that comprise the cities and towns. Huge investments are being committed in new infrastructure projects in developing countries. Development of infrastructure enhances the scope of utilizing underemployed resources, besides creating new investment opportunities. Infrastructures are long-life assets and are designed to withstand normal variability in climate regime. However, climate change can affect both average conditions and the probability of extreme events, temperatures, precipitation patterns, water availability, flooding and water logging, vegetation growth, land slides and land erosion in the medium and long run which may have serious impacts for the infrastructure. Infrastructure displays some special characteristics that have a strong bearing for the adaptation policies for protecting it against the likely impacts.

Infrastructure – Special Characteristics

The word 'infra' means below and 'infrastructure' means the support services below the real economic

Infrastructure is at risk due to climate change.

structure. Though the concept of infrastructure has been extensively used in the literature of economic development, it has not been explicitly defined in a precise and generally accepted manner. A number of interchangeable terms such as social overhead, economic overhead and basic economic facility have been used to denote services, which are generally identified with infrastructure.

Some of the basic characteristics of infrastructure facilities can thus be defined as:

- *Essential but not directly productive:* Infrastructure facilities are universally required for carrying out any kind of production, yet they themselves do not produce goods for final use. They provide support to the directly productive activities and are, thus, in the nature of overhead costs.
- *Pre-requisites of development:* Infrastructure facilities are normally created ahead of demand. Due to their universal requirement they are often considered as necessary pre-requisites of development. The expansion of production activities is unlikely to take place, beyond a level, without these services.
- *Non-importable:* More often than not, the technical nature of these facilities is such that necessitates their creation and supply at the very place of their use. Electricity can be cited as an exception, which can be transported but requires specialized infrastructure in place.
- *Lumpiness:* Infrastructure cannot be built in bits and pieces and has to be provided in a minimum size. This feature emanates from what can be described as technical indivisibility. In general, a minimum quantum of investment, which is often large, is required for the creation of infrastructure. A corollary of indivisibility and lumpy investment is that the per unit cost of services generated by infrastructure declines over a very large range of production.
- *External Economies:* Another distinguishing feature of infrastructure is that it generates external economies, i.e., ‘services rendered free’. The benefits from infrastructure are sometimes so widespread that it is difficult to identify each and every beneficiary. Hence, it is said that investment in infrastructure is profitable for society as a whole.
- *Provision by state:* Due to very high investment involved and inability to generate attractive return to the investor, infrastructure facilities generally require investment by the government. Historically the world over, most of the services have been developed with the initiative of the states.

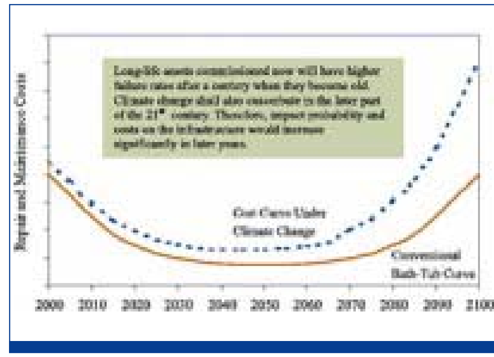


Figure 3.40: Infrastructure maintenance and impact costs.

In addition to the above characteristics, infrastructure projects have a long gestation period and a comparatively long life span. Any asset like infrastructure, that has a long life, has a tub-shaped cost curve for repair and maintenance. In the initial stabilization period, it may require frequent maintenance. The maintenance requirement decreases once the system has stabilized (Figure 3.40). It increases again due to wear and tear, as the asset reaches the end of its useful life. Attention to climate change impacts becomes important, since these may be more pronounced in the later part of the 21st century (IPCC, 2001b). These two effects coupled together, would increase the economic impact on infrastructures. Thus, developing countries need to take the investment decisions for infrastructure development very carefully, because these decisions result in long-term irreversible commitment of resources.

Infrastructure development in India

Economic growth in India demands development of its infrastructure. In the light of the continued need for development of infrastructure in India, successive five-year plans have devoted a large and increasing volume of outlays for the development of economic, social and institutional infrastructure. The following broad generalization can be made about the trend of investment in infrastructure items over the planning period.

The major share of plan outlay has gone for the development of a few infrastructure items that reflects the high priority given to some sectors. In the first two five-year plans, nearly two-thirds of the total plan outlays were devoted to social and economic infrastructure. In the later plans, this declined to about three-fifths of the outlay. Economic infrastructure (transport, power, irrigation and communication) has claimed a lion's share—around 45 per cent of the plan outlays. Within the economic infrastructure, power and transport have received the largest share. Social infrastructure has received relatively less attention, claiming less than one-sixth of the plan outlays. The pattern of plan outlays on infrastructure in the 1950s is distinctly different from that of the later plans. However, there is stability in the pattern of plan outlays, though certain marginal shifts have occurred from one plan to the other.

The Ninth Plan Working Group on Housing had estimated the investment requirement for housing in urban areas at Rs 526 billion (US$ 11.5 billion). The India Infrastructure Report estimates the annual investment need for urban water supply, sanitation and roads at about Rs 280 billion (US$ 6.15 billion) for the next 10 years. The Central Public Health Engineering has estimated the requirement of funds for a 100 per cent coverage of the urban population under safe water supply and sanitation services by the year 2021 at Rs 1,729 billion (US$ 37.9 billion). Estimates by Rail India Technical and Economic Services (RITES) indicate that the amount required for urban transport infrastructure investment in cities with population 100,000 or more during the next 20 years, would be of the order of Rs. 2,070 billion (US$ 45.4 billion).

Obviously, these massive investments cannot be located from within the budgetary resources of central, state and local governments. Private sector participation and access to international finances are, therefore, required for infrastructure development projects. As a result, investment opportunities are arising in the infrastructure sector, especially in roads, ports, energy, telecommunications and urban services. India may require Rs 9,800 billion during 2001-2006 to meet the projected growth in demand for infrastructure (India Infrastructure Report, 1996).

Some recent initiatives of large-scale infrastructure development in India include the development of the national highways network. Such infrastructure projects require huge investments. The national highways development project for four/ six-laning of around 13,146 km of road network, with another 1,000 km of port and other connectivity, is expected to cost Rs 540 billion (US$ 11.8 billion). More than 2,100 km has already been completed over the last three years and another 5,000 km are under various stages of completion. More than US$ 3.5 billion have been spent and/or committed. The river linking project is estimated to require a Rs. 5,560 billion (US$ 122 billion) investment over next the 10 years. This project has been envisaged in the current climatic regime and assumes the availability of water in the perennial Himalayan rivers. If the climatic changes predicted by international scientific assessment (IPCC, 2001b) were to be realized over the present century, the monsoon and rainfall patterns would alter and the glaciers would recede, thus changing the annual water flow patterns in the sub-continental rivers. This would alter the project's assumptions and the costs and benefits assessment.

Huge investments in infrastructure, having a long life span, are presently being planned without any conscious analysis of climate change-related impacts on them. It is indisputable that long-term climate changes are likely to have impacts on infrastructure. All over the world, extreme weather events are a major cause of damage to infrastructure. In developing countries, governments have to bear the losses arising from this damage to infrastructure, since currently 95 per cent of infrastructure is government-owned and it bears the responsibility for repair and maintenance. Even for privatized infrastructure, the *force majeure* provisions largely allocate financial responsibility for catastrophe risk to governments. An inevitable result of the increased damages to infrastructure from climate change will be a dramatic increase in resources needed to restore infrastructure. A developing economy like India has to take these issues into consideration while formulating appropriate policies.

Methods and models

The present assessment of climate change impacts on infrastructure has been analyzed by developing an impact matrix. The matrix approach facilitates the identification of indicators which may have impacts for a particular case study. A matrix approach with indicator analysis is also preferable, because indices make it possible to compare two or more complex, multifaceted systems at one time by analyzing the interactions among the systems and converting the information related to varied impacts in a single observable outcome. While this process of reductionism enhances the understanding about the phenomenon, it works contrary to both the complex behaviour of the system and potentially disparate nature of impacts. However, modelling requires this simplification of complex realities and the matrix approach provides the required simplification mechanism.

The stages involved in the design of the matrix include:

- Defining existing conditions/components.
- Projecting and estimating likely future changes.
- Taking each component one by one and applying change (as a 'thought experiment').
- Recording the extent of interactions.
- Identifying major problem areas.

Traditionally, the impact matrix approach used for environmental assessment carries out an analysis of the impacts of economic activities on the environment. A conventional impact matrix explores a one-way relationship of the effect of human activities on the environment. The reverse link is most often ignored. For the present assessment, a reversed matrix has been developed, which links the impacts of change in environmental variables to the project activities. A schematic diagram of the matrix is given in Figure 3.41.

The first quadrant in the above matrix indicates the conventional impact matrix, where the impact of project components on the environment is analyzed. The first and second quadrant show the interrelationships of the environmental variables and project components. The fourth quadrant shows the impacts of changes in the environmental variables on the project components.

Impact on Transport sector

Climate change impact on transportation infrastructure and the operation of transportation systems may be divided into three categories: the effects of climate on operations; the effects of sea-level rise on coastal facilities; and the effects of climate on infrastructure.

A future climate with an increased number of rainy days, rainstorms and higher rainfall intensity may increase vehicular accidents and injuries in accidents, and result in longer travel time and increased delays. The effect of climate change on transport is not very clear. However, transportation by air is known to be sensitive to adverse weather conditions; major system-wide effects sometimes follow from flight cancellations, rerouting, or rescheduling. There is a high level of confidence that sea-level rise will increase the cost of protecting infrastructure located in the coastal regions.

Dependent Variables / Forcing Variables	Environmental Variables	Project Components
Environmental Variables	2	4
Projects Components	1	3

Figure 3.41: Reverse impact matrix.

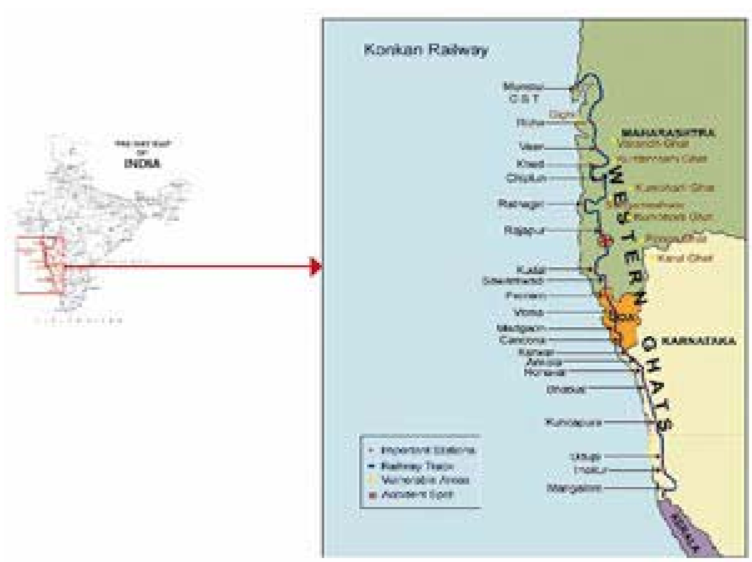
Transportation operations are sensitive to local weather conditions. Fog, rain and snow slow down transport movements and increase risks of accidents. In addition, maintenance costs and durability of infrastructure are also dependent on weather events. Changes in frequency and intensity of extreme events such as hurricanes, floods, high-speed winds and cloudbursts may have significant impacts on the safety and reliability of transportation. All these impacts are location-specific and the infrastructure located in different regions will experience different intensity of impacts.

In the following section, a case study of climate change impacts for the Konkan Railway has been presented. This work has been carried out applying the proposed reversed impact matrix. An analysis of the currents conditions, lessons from the past climate variability, potential climate change impacts, knowledge and information gaps, and the point of view of the stakeholders have also been presented.

Impacts on Konkan Railway

Konkan is a coastal strip of land bounded by the Sahyadri hills to the east and the Arabian Sea to the west in the states of Karnataka, Goa and Maharashtra. It is a region with rich mineral resources, dense forest cover, and a landscape fringed with paddy, coconut and mango trees. This railway project was conceived with the objective of bridging the 'Konkan gap' and reducing the distance and travel time between Mumbai, and coastal Karnataka and Kerala (Figure 3.42).

Konkan Railway: The Layout and Vulnerable Spots



The 760 km long Konkan Railway on the western coastal ghats of India is an engineering marvel with 179 main and 1,819 minor bridges, 92 tunnels (covering 12% of the total route) and over 1,000 cuttings (224 deeper than 12 metres). The longest tunnel is 6.5 Km long and the longest bridge is over 2 km. The pillars of the tallest viaduct bridge are more than 64 metres high, taller than Qutab Minar.

Presently 20% of repair and maintenance expenses on tracks, tunnels and bridges are due to climatic reasons.

A recent accident on 21st June 2003 night (see ⊕ on the map), resulting in over 50 deaths, was caused by landslide at a deep cutting due to incessant heavy rains, presumably higher than the system's adaptive capacity. Consequent to the accident, maximum permissible speed of trains has been reduced from 120 Km/h to 75 Km/h.

200 mm rainfall within 24 hours increases vulnerability (Nagrajan et al., 2000) (see ■ present vulnerable regions around the northern corridors as on the map). Future rainfall pattern shows that such events are likely to occur more frequently and with higher intensity (chapter 3 of this book).

Adaptation measures should also consider vulnerable spot identification based on future climate change projections.

Figure 3.42: Konkan Railway: Layout and vulnerable spots.

The Konkan Railway is a broad gauge (1,676 mm) single line, between Roha (about 150 km south of Mumbai) and Thokur (22 km north of Mangalore), a distance of 760 km, built at a cost of about Rs 34 billion (US$ 745 million). It has 59 stations, 179 major bridges (total linear waterway 20.50 km) and 1,819 minor bridges (total linear waterway 5.73 km). This is for the first time that Indian Railways have constructed tunnels longer than 2.2 km and there are nine such tunnels in the project (KRCL, 1999). The Konkan Railway Corporation Limited (KRCL) track passes through more than 1,000 cuttings[4], with 224 being deeper than 12 metres. All these deep cuttings have been declared as vulnerable spots by KRCL after the June 2003 accident.

Impact analysis

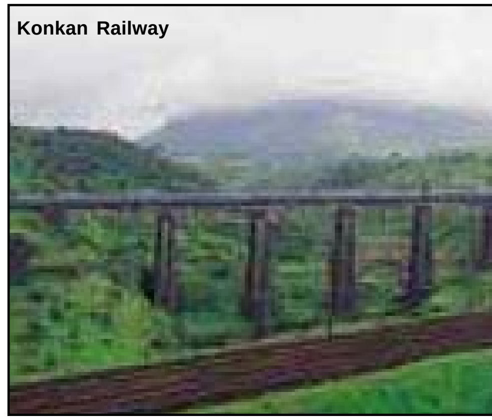
The Western Ghats, through which the Konkan Railway passes, experience moderate to heavy rainfall and its marine ecosystems are sensitive to climate

Table 3.13: Climate Change Impacts on Konkan Railway.

Climatic Parameter	Impact Parameter	Intervening Parameter	Impact on KRC
Temperature Increase	High evaporation rate	Stability and strength of the building materials	Buildings get weakened. Frequent repair and maintenance
	Surface and ground water loss	Crop productivity in the region may be affected	Agricultural freight traffic
	Need for air-conditioning	Passenger traffic may shift to air-conditioned class	Affects efficiency, carrying capacity and composition.
Rainfall Increase	Ground and surface water-level change	Flooding and water logging, erosion reduces the quality of land cover	Buildings affected, structural damages may take place. Increased maintenance and other related costs
	Improved water availability in the region	Agricultural production	Changes in agricultural freight traffic
	Humidity increase	Uncomfortable climatic conditions, vegetation growth along the track	Passenger traffic affected, increased maintenance cost
Sea-level Change	Land erosion	Tracks tunnels and bridges may be affected	Increased maintenance,
	Flooding	Land instability and land slides	Damage to infrastructure, reconstruction and relocation
	Water logging		Risk of delays increase
Extreme Events	Cyclone and high-velocity winds and storms	Damage to buildings, communication lines, etc	Disruption of services, repair and reconstruction costs
	Cloudbursts	Land erosion, floods, and landslides	Extensive damage to infrastructure, high cost of repair and reconstruction

[4] Small hillocks are cut through to construct passage for the railway track duly maintaining reasonable slope for the track. These passages are called cuttings. Cuttings are like top-open tunnels, with spread-out slopes on either side. Some cuttings are deeper than 12 to 15 metres. Such deep cuttings pose higher safety hazards due to higher possibilities of water logging and landslides. Cuttings cave in mostly due to excessive rains. Unstable cutting-slope and geological characteristics of the soil determine its sensitivity to rains. Adaptation measures include regular monitoring during the rainy season, temporary speed restrictions on the trains passing through these cuttings, nylon-net erection and retaining wall construction to trap sliding boulders, removing precariously placed boulders in anticipation, appropriate drainage construction and maintenance, further easing out and consolidation of the cutting-slopes, paving and sowing of grass on the cutting-slopes.

changes. Although many studies were carried out to analyze the impacts of the Konkan Railway project on the surrounding ecosystems and environment, none of these have analyzed the environmental impacts on the Konkan Railway. The present assessment explores the potential impacts of climate change on the Konkan Railway infrastructure by identifying the relationship of the various climate change parameters with the likely impacts on the Konkan Railway, through a series of impact and intervening parameters (Table 3.13).


Konkan Railway

Cause-effect analysis

The cause-effect analysis was carried out through a reverse causal matrix, where various identified indices were assessed for their capacity to force changes in the other elements, through a qualitative approach. Table 3.14 shows the causal analysis for Konkan Railway for 10 identified indices. The table shows a two-way matrix, where 'L' denotes a weak link, 'M' a moderate link and 'H' a strong link. Rows show the forcing variables and the columns dependent variables. The strength of the causal link was determined in consultation with the officials of Konkan Railway. A total of eight senior officials were interviewed. A two-stage process of interviewing was adopted for this purpose. In the first stage, relevant causal variables were identified, and in the second, the strength of the link was determined. The analysis matrix presented here shows the perceptive importance assigned by the people working in the field and therefore no quantification of the relative strengths of the linkages has been attempted.

The analysis carried out with the help of the impact matrix shows that low dependence and high-forcing factors such as rainfall are the major climatic drivers having impacts on Konkan Railway. This factor is influenced by elements external to the Konkan Railway and is beyond the control of the system. Other factors such as temperature, sea-level rise and extreme events have complex feedback loops and result in high forcing. Further research may be needed to improve the understanding of these linkages. On the contrary, factors such as landslides have a high-forcing effect, but are also highly influenced by other elements within and outside the system, such as precipitation patterns, geological characteristics of the soil, stabilization and prevention mechanisms in place. Factors, such as traffic volume, which have a high dependence on all other factors, are very important for Konkan Railway.

	Dependent variables	Environmental Variables							Project Components		
	Forcing Variables	Temperature	Rainfall	Sea level rise	Extreme events	Water logging	Vegetation growth	Land slide	Safety/Efficiency	Maintenance	Traffic volume
Environmental Variables	Temperature		L	M	L	–	L	–	–	–	L
	Rainfall	L		–	M	M	M	H	L	L	M
	Sea level rise	–	–		–	M	L	M	L	–	L
	Extreme events	–	L	–		M	–	M	L	–	M
	Water logging	–	–	–	–		–	L	L	–	M
	Vegetation growth	L	L	–	–	–		L	–	L	–
	Land slide	–	–	–	–	M	L		M	L	H
Project Components	Safety/Efficiency	–	–	–	–	L	–	L		M	M
	Maintenance	–	–	–	–	M	L	H	H		M
	Traffic volume	–	–	–	–	–	–	–	L	M	

Table 3.14: Causal matrix for impact analysis for Konkan Railway

From the matrix it is clear that the most relevant factor for measurement of potential impacts is rainfall, which has a strong negative influence, and preventive maintenance, which is a strong positive influence. Rainfall is highly influenced by external factors and cannot be forced by the factors internal to the system, whereas preventive maintenance is internal to the system and can help in minimizing the extent of impacts.

After identifying the forcing variables, the next step is to explore critical thresholds to determine when the risk of a climate change impact becomes 'dangerous'. These thresholds are case and climate change scenario-specific. These indicate decision points where additional preventive measures become imperative. For the Konkan Railway case, rainfall has been identified as the main forcing variable. Based on the studies carried out in the past, the rainfall threshold for landslides in the Konkan region has been identified as more than 200 mm precipitation in 24 hours. However, rainfall alone is not sufficient for causing landslides, which can be influenced by many other factors such as geology, soil structure, vegetation cover and slope.

Every year during the monsoon, train operations are disrupted due to water logging and landslides. There are numerous instances of trains running late due to preventive speed restrictions and disruptions during the rainy season every year. An analysis of the past data indicates that on an average, the operations are suspended for about a week during the monsoons because of such problems along the track. One of the major traffic suspensions was for 14 continuous days between 11-25 July 2000, due to landslides at 36 locations caused by more than 300 mm rainfall on a single day. The expected losses were estimated to be about Rs 100 million (US$ 2.2 million). There were a total of 140 reported incidences of landslides during the entire monsoon season in 2000.

Konkan Railway authorities annually identify vulnerable locations where preventive maintenance is carried out before the onset of monsoon, to deal with any such calamity. Based on experiences over the years, the number of identified vulnerable locations has varied between 60 and 120 every year. In the year 2002-2003 more than 200 vulnerable spots have been identified. Several preventive adaptation activities[5] have been undertaken at these vulnerable locations to minimize adverse impacts. The purpose is to reduce the number of such locations gradually and stabilize the track over the years for trouble-free train operations.

Climate change Impacts on Energy

The energy sector is highly dependent on temperature conditions and this is probably, where climate change could have very strong direct impacts. The regional temperature would change significantly, thus affecting the future energy consumption behaviour. In the residential and building sector, a major energy demand is expected to be for space cooling and heating. Air-conditioning and refrigeration load is closely related to the ambient air temperature and will thus have a direct relation to temperature increase. Temperature increase in the northern mountainous region, where space heating in winter is required, might result in some saving in heating energy. This will be more than compensated by increased energy requirement for space cooling in the plains, thus resulting in a net increase.

Higher income levels will further increase demands for air-conditioning. There are many energy sources for space heating, including coal, biomass and electricity. However, the main source of energy for cooling is electricity. A higher demand for air-conditioning will thus result in an increased electricity demand. Similar to the residential sector, the commercial and industrial sector will also experience an increased load for air-conditioning and refrigeration due to temperature rise.

Many sectors affected by climate change will have indirect impacts on the energy sector. A major sector that causes indirect impact on energy is agriculture. Agriculture is very sensitive to any type of climate changes. Climate change in India will result in temperature rise and a changing precipitation pattern. The evaporation rate is also expected to rise because

[5] These include regular monitoring during rainy season, temporary speed restrictions on the trains, nylon-net erection and retaining wall construction to trap sliding boulders, removing precariously placed boulders on cutting-tops in anticipation, appropriate drainage construction and maintenance, further easing out and consolidation of the cutting-slopes, paving and sowing of grass on the cutting-slopes.

of the temperature increase. This may be countered by increase in rainfall and humidity in some regions. All these put together will affect the water requirement for agriculture which will be greater, resulting in a higher demand of energy for irrigation. The residential water demand is also expected to increase, which would in turn affect the energy required for the water supply system.

Additional electricity generation due to climate change, over and above the electricity generation in 2100, is estimated to be 64 TWh, which is 1.5 per cent of the reference scenario generation for the same year. The domination of coal-based generation continues due to the reliance on domestic resources for energy supply and a major share of this added generation requirement is taken up by the coal-based generation. The economic linkages with coal are also very strong due to the large infrastructure associated with the mining industry, coal transportation network, generation equipment manufacturers, etc., and coal remains competitive in the long run.

As renewable technologies including hydro, wind, cogeneration, other biomass technologies, solar and geothermal, are expected to reach plateau by this time, fuel-mix changes in the energy sector would largely depend on development of nuclear power and new sources of energy such as fuel cells, fusion etc. over a period of time.

Risk and Insurance

The insurance sector has participated in covering the risks of the large-scale infrastructure projects against future uncertainties. Climate change increases risks for the insurance sector, but the effect on profitability is not likely to be severe, because insurance companies are capable of shifting changed risks to the insured, provided that they are 'properly and timely informed' on the consequences of climate change. For example, in the event of a catastrophic event, the insurance sector reacts to increased risk and large losses by restricting coverage and raising premiums. It has been shown by various authors that the increased climatic variability necessitates higher insurance premiums to account for the higher probability of damages.

Despite the costs, there has been a great deal of excitement about the potential of insurance and other forms of risk transfer for hedging the risks of extreme weather-related and other disasters facing developing countries. Governments carry a large and highly dependent portfolio of infrastructure assets, some of which are critical for restoring economic growth, and for the same reason, as firms, they may wish to reduce the variance of their disaster losses by diversifying with insurance and other risk-transfer instruments.

Lacking more attractive financing alternatives, the government benefits from risk transfer, since it reduces the variability of its disaster losses, but risk transfer requires resources that could otherwise be invested in the economy. In terms of economic growth, there is thus an inherent trade-off: a reduction in funds spent on current growth permits a government to protect itself against extreme future losses.

Conclusions

There is a need for building awareness about the potential impacts among the concerned people, and developing good quality databases. Systematic efforts are required to study the impact assessments of different climatic parameters. Studies about future projections of changing regional climate provide insights for methodological developments, including models for integrated assessment and GIS-based computer algorithms for supporting policy assessments at regional levels.

The climate change impact analysis on energy infrastructure indicates that a rise in average temperature increases the need for space cooling for buildings and transport sectors. The variability in precipitation can also impact the irrigation needs and consequent demand for energy. These would increase electricity demand, and consequently result in the need for higher power capacity. The demand for air-conditioned transport and their increased use may result in lower fuel efficiency, increasing petroleum product consumption. The increased energy demand will result in higher emissions. The assessment for India suggests an increase of around one per cent annually, which though not substantial, is still significant for examining the reverse links and feedback with climate change.

The infrastructure sector is a vital sector, where huge investments are being committed in developing countries. The sector creates long-life and open-to-weather assets that will face increasing impacts from the changing climate. It would be prudent for developing country policy-makers to pay attention to protecting these assets, which may otherwise cause significant welfare losses to future generations. Myriad adaptation strategies are needed. These would include the incorporation of future climate extremes in the project design parameters in the immediate term; improved operational and maintenance practices in the near term; and improved climate predictions and creation of insurance markets in the long term.

Chapter 4

Research and Systematic Observation

Research and Systematic Observation

Chapter 4

India's agrarian economy, under favourable tropical climatic conditions of the Asian summer monsoon and with a majority of the population engaged in agriculture, has necessitated a closer linkage with weather and climate since the Vedic period. This necessitated a very early interest in weather observations and research. Ancient Indian literature by Varahmihir, the '*Brihat-Samhita*', is an example of ancient Indian weather research.

Modernized meteorological observations and research in India was initiated more than 200 years ago, since 1793, when the first Indian meteorological observatory was set up at Madras (now Chennai). A weather network of about 90 weather observatories was established when IMD was formally set up in 1875. It was decided to create a separate agricultural-meteorology directorate in the IMD in 1932 to further invigorate the observation network. Many data and research networks have been established over the last century for climate-dependent sectors, such as agriculture, forestry, and hydrology, rendering a modern scientific background to atmospheric science in India. The inclusion of the latest data from satellites and other modern observation platforms, such as Automated Weather Stations (AWS), and ground-based remote-sensing techniques strengthened India's long-term strategy of building up a self-reliant climate data bank.

India's observational and research capabilities have been developed to capture its unique geography and specific requirements, and also to fulfil international commitments of data exchange for weather forecasting and allied research activities.

RESEARCH

The Government of India attaches high priority to the promotion of R&D in multidisciplinary aspects of environmental protection, conservation and development including research in climate change. The MoEF is the nodal ministry for the subject of climate change in India. Several central government ministries/departments promote, undertake and coordinate climate and climate related research activities and programmes in India through various departments, research laboratories, and universities (Figure 4.1). Research at autonomous institutions of excellence such as the Indian Institutes of Management (IIMs), Indian Institutes of Technology (IITs), and Indian Institute of Science (IISc); and non-governmental and private organizations provide synergy and complementary support. Indian researchers have contributed significantly to assessment reports of the IPCC for over a decade. The ensuing sub sections provide some details of climate and climate-change research being carried out in various modes.

Institutional arrangements

The MoEF, Ministry of Science and technology (MST), Ministry of Agriculture (MoA), Ministry of Water Resources (MWR), Ministry of Human Resource Development (MHRD), Ministry of Non-conventional Energy (MNES), Ministry of Defence (MoD), Ministry of Health and Family welfare (MoHFW), and Indian Space Research Organization (ISRO) are the main ministries of the Government of India which promote and undertake climate and climate change-related research in the country. The ISRO is under the direct governance of the Prime Minister and support all the above agencies with satellite-based passive remote sensing.

The MoEF, MST, MHRD and MOA are operated under the umbrella of coordinate many premier national research laboratories and universities. The most prominent being the 40 laboratories of the Council of Scientific and Industrial Research (CSIR),

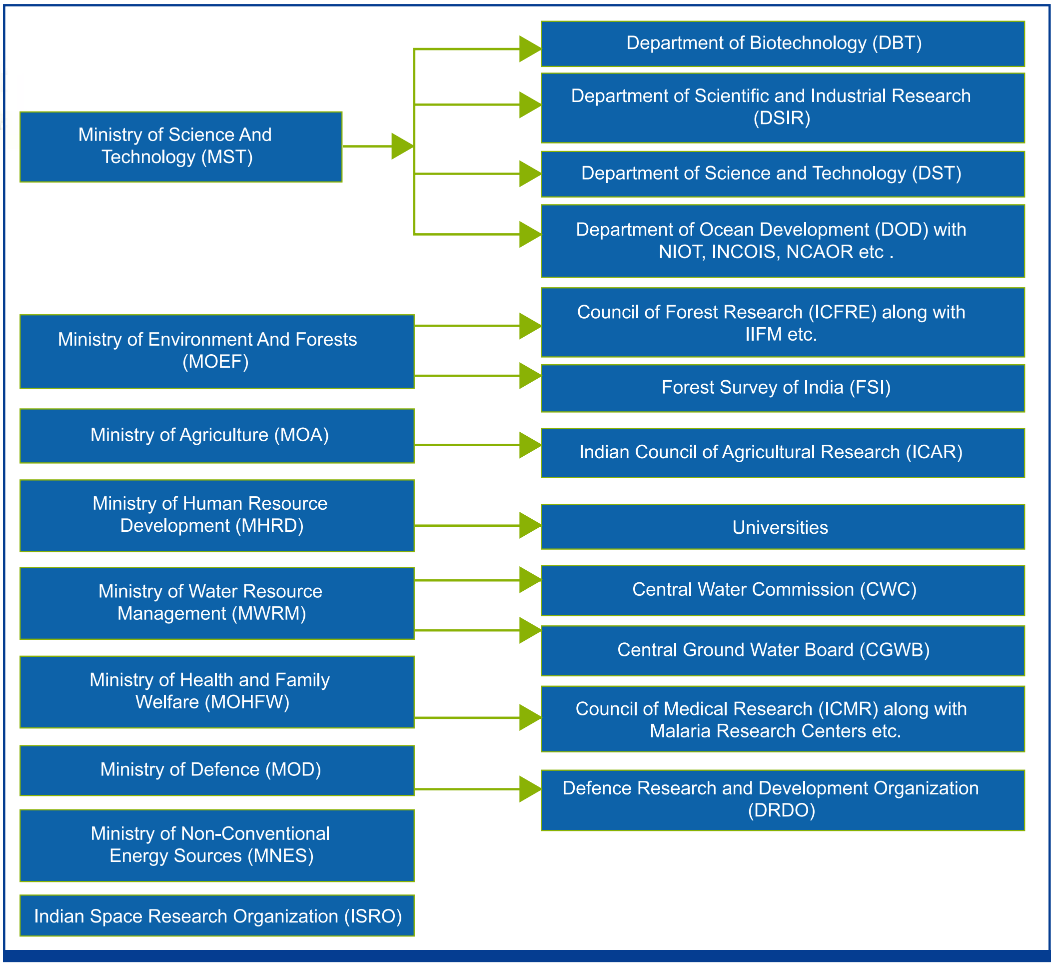


Figure 4.1: Climate and climate change research institutions in India.

an autonomous body under the MST; and the vast network of the Indian Council of Agricultural Research (ICAR) under the MOA. The CSIR is the national R&D organization which provides scientific and industrial research for India's economic growth and human welfare. It has a countrywide network of 40 laboratories and 80 field centres. The ICAR network includes institutes, bureaus, national research centres and project directorates employing about 30,000 personnel. 30 state agricultural universities employ about 26,000 scientists for teaching, research and extension education; of these over 6,000 scientists are employed in the ICAR supported/ coordinated projects.

The Department of Science and Technology (DST) under the MST coordinates advanced climatic and weather research and data collection over the Indian landmass. There are three premier institutions under DST that are solely dedicated to atmospheric science viz. the IMD, the National Centre for Medium Range Weather Forecast (NCMRWF) and the Indian Institute of Tropical Meteorology (IITM).

The IMD possesses a vast weather observational network and is involved in regular data collection basis, data bank management, research and weather forecasting for national policy needs. The NCMRWF conducts atmospheric and climatic research with particular emphasis to develop indigenous, customized GCMs and RCMs for the Indian subcontinent and to forecast the medium-range weather for socioeconomic sectors that are directly affected by climate, such as agriculture and tourism for short-term policy-making. The NCMRWF is also engaged in agriculture-meteorological advisory services to farmers through in-house modelling and forecast (on a daily basis) for different Indian crop systems. It runs an agro-advisory services network with ICAR, which provides daily weather forecasts to farmers. The IITM is involved in various kinds of advanced climate and weather research; including climatology, hydrometeorology, physical meteorology and aerology, boundary layer, land surface processes, atmospheric electricity, climate-simulations, climate and global modelling/ simulations. Research in advanced instrumentation and observational techniques is also being carried out at the IITM along with other theoretical studies.

In addition to these dedicated atmospheric research institutes, the DST funds a parallel research network under the aegis of CSIR which has several research institutions for various scientific disciplines dedicated to applied scientific and industrial research. Atmospheric, environmental and oceanic research is one of its areas of focus and has been taken up by its institutions like the National Physical Laboratory, the National Environmental Engineering Research Institute, the Centre for Mathematical Modelling and Computer Simulations (of National Aeronautical Laboratory), the National Institute of Oceanography, and the National Geophysical Research Institute.

The Department of Ocean Development (DoD) was established in 1981 to create a deeper understanding of the oceans, to develop technology and technological aids for harnessing resources, and to understand various physical, chemical and biological oceanic processes. The DoD regularly conducts atmosphere and ocean-related research and observational experiments over the vast Indian coastal zone, and provides real-time data for cyclones and storm surges to the government and other organizations. The DoD supports national, regional and international data generation and exchange programmes. The DoD also maintains the Indian Antarctic Station—*the Maitri* and has set up a dedicated research institution in India to undertake research for the pristine Antarctic environment and climate. In order to fulfill the objectives of the international ocean policy, the department has been promoting, funding and implementing major R&D programmes through various agencies, NGOs and universities.

Integrated environmental, ecological and forestry research vis-à-vis climate change is coordinated by the MoEF. Under the aegis of ICFRE, the ministry runs several research institutions dedicated to environmental, forestry and ecological research. The ICFRE mandate is to organize, direct and manage the research and education in the Indian forestry sector. It is actively engaged in advanced research with focused objectives of the ecological and socio-economic human needs of present and future generations towards climate-related objectives of water and the microclimate. Research on absorption of GHGs (carbon sinks and reservoirs) and mitigation of global warming through increasing forest reserve, are among the focused agenda of ICFRE. It is committed to protect forests against the harmful effects of pollution, including air-borne pollutants, fires, grazing, pests and diseases, in order to maintain their full multiple values.

Agriculture production sustainability, enhancement and related research are thrust areas of research under the MOA. The ICAR, as the premier institution for agricultural R&D, is working on different aspects of agriculture sustainability and meteorological research, including field research and modelling for Indian crop systems under the projected climate change.

The MWR coordinates surface and groundwater-related data generation, management and dissemination; technology implementation and all other related research activities through its organizations, such as the Central Water Commission, the Central Ground Water Board, the National Water Development Agency, the National Institute of Hydrology, the Central Water and Power Research Station, the Central Soil and Materials Research Station, and various river boards. The ministry also funds advanced research programs of universities, autonomous research institutions (such as IITs) and NGOs for water-related activities. The ministry, through its National Commission for Water Resources Development and other collaborative research activities, is conducting water resource assessment, including evaluation of impacts of climate change on Indian water resources.

The MHRD, through academic institutions like universities and IITs, operates several research programmes on weather, climate, atmosphere, environment, ecology, agriculture, forestry and related issues. These institutions are involved in climate research by developing infrastructure, participating in atmospheric observations, and modelling efforts on climate simulations using various internationally recognized GCMs/ RCMs. They conduct project-related and need-based atmospheric observations from time to time.

The MoHFW, through the Malaria Research Centre, has initiated climate change related research due to the threat of the spread of anthropogenic health and vector-borne diseases, and efforts for eradication of these diseases. The Centre works in collaboration with various institutions that are actively involved in mainstream climate-change research.

The MOD conducts atmospheric and oceanic research with particular focus on defence interests. In addition, the ministry also funds other agencies for advance research on weather, climate, environment and oceans.

Other than these mainstream research initiatives, the MHRD funds the academic set-up in India, including universities and the IITs. These are involved in climate research either by developing the infrastructure, or by participating in observations or by the effort of climate simulations using various internationally recognized GCMs / RCMs. They carry out some object-oriented atmospheric observations from time to time for their research need. The universities and IITs are generally engaged in project-mode, objective-oriented research-programmes.

Other than the government ministries, several autonomous institutions and NGOs are engaged in climate change-related research. IIM, Ahmedabad and IIT, Delhi are front-runners. The Indira Gandhi Institute of Development Research, an institution established by the Reserve Bank of India (RBI) is engaged in the estimation of the climatic factors that may affect India's development pathways. NGOs like The Energy and Resource Institute, Winrock International India, Development Alternatives, Centre for Science and Environment, and the Society for Himalayan Glaciology, Hydrology, Ice, Climate and Environment operate in project-based research mode on climate change vulnerability, impacts and mitigation.

Apart from the Indian initiatives, climate change research promoted by international organizations like the World Climate Research Program (WCRP), International Geosphere Biosphere Programme (IGBP), International Human Dimension Program (IHDP) and DIVERSITAS are being strongly supported by various Indian agencies like Indian Climate Research Program (ICRP) under DST, National Committee- International Geosphere Biosphere Programme (NC-IGBP) constituted by Indian National Science Academy (INSA) and Geosphere-Biosphere Program (GBP) of ISRO. Agencies like CSIR, also provides infra-structural and financial support to carry out research in the area of global change.

Atmospheric trace constituents

In India, a number of research activities related to the measurements of atmospheric trace constituents are being carried out by different national laboratories, institutions and universities to investigate various research problems, individually as well as jointly, by the financial support provided by different government and international agencies. A classic example of such a research endeavour is the methane emission measurement from Indian rice paddy fields, which was initiated as a result of a national campaign in 1991 in which several institutions collaborated. Over a period of time, measurements of methane emission from rice paddy fields have been continuing with the involvement of new institutions. The impact of this cooperative study in the international scenario was overwhelming, by establishing that the total methane emission strength from Indian rice paddy fields is about 4 Mt which is much lower than the initial international estimates of about 37 Mt.

The determination of GHG emissions from different sectors such as energy, industries, enteric fermentation, manure management, forestry, land use, land-use change and waste, are being carried out by a number of research organizations in India. These include the National Physical Laboratory, the National Chemical Laboratory, the Indian Institute of Science, the Central Fuel Research Laboratory, the Jadavpur University, Kolkata University, the Central Leather Research Institute, the National Dairy Research Institute, the Indian Agriculture Research Institute, the Regional Research Laboratory, the Central Rice Research Institute, and the Central Mining Research Institute, among others. However, considering the vast coverage these studies need to address, due to the diverse mix of technology, geographical and social parameters, these studies are just a beginning and would require strengthening both in terms of institutions and financial resources to meet the research requirement.

For the measurement of aerosols and precipitation and their associated properties and impacts, a number of research organizations are well-equipped, for example, the National Physical Laboratory, the Physical Research Laboratory, the Bhabha Atomic Research Centre, IIT, Mumbai and Chennai, the Indian Institute of Tropical Meteorology, the Regional Research Laboratory-Bhubaneswar, the Space Physics Laboratory, IISc, the Dayalbagh Educational Institute and Rajasthan University. Several Indian research organizations are participating in a new ISRO-GBP activity (Indian Space Research Organization's Geosphere Biosphere Program, which also supports global change related studies), named

Aerosol size distribution measuring equipment—QCM cacade impactor at one of the Indian laboratories.

High volume sampler and aerosol chemical analyser of one of the Indian laboratories.

as Aerosol Budget and Radiation Studies (ARBS) program to measure ambient concentrations of atmospheric trace gas species and aerosols and their properties in India.

Efforts have also been made in India to establish different monitoring sites at key locations to monitor ambient trace gas and aerosols concentrations and their trans-boundary flow. In this direction, the National Physical Laboratory, with the help of several other institutions, is in the process of establishing four monitoring stations at Hanle in Laddakh using the infrastructure facilities developed by the Indian Institute of Astrophysics, at Darjeeling at the High Altitude Research Center of Bose Institute; at Sunderbans with Jadavpur University; and at Port Blair with Central Electro-Chemical Research Institute. The Physical Research Laboratory and Space Physics Laboratory have also established monitoring facilities at Port Blair.

Climate Related Environmental Monitoring (CREM) is a multi-agency project to monitor GHGs and aerosols in India on which policy decisions regarding climate management can be based in future. The project aims at establishing a network of stations in India to generate primary data on GHGs and aerosols on a long-term basis. Such data is of vital interest

High altitude Hanle observatory in Ladakh is being proposed to be used for monitoring ambient trace gas and aerosol concentrations.

with regards to climate change studies and to create a sound database that can be used in future climate change negotiations in the UN framework.

CREM is a programme to be implemented by IMD as a nodal agency in a collaborative mode involving the following participating agencies.

- Indian Institute of Tropical Meteorology (IITM), Pune.
- Jawaharlal Nehru University (JNU), New Delhi.
- National Physical Laboratory (NPL), New Delhi.
- Regional Research Laboratory (RRL), Bhubaneshwar.

A pilot project in CREM is being implemented by establishing on-site monitoring station at GB Pant University of Agriculture and Technology, Ranichauri, Tehri Garhwal (Uttaranchal), for GHGs, and at Delhi for aerosols in the first year. It is planned to create a network of such facilities covering the entire country. This network will monitor gases like CO_2, CH_4, N_2O, O_3 and aerosols.

Under the aegis of the Asia Least-cost Greenhouse Gas Abatement Strategy (ALGAS) study and subsequently the Initial National Communication project, India-specific emission coefficients have been developed, such as those for methane emissions from paddy cultivation, CO_2 emissions from Indian coal, road transport, and cement manufacturing. Prior to these, extensive methane measurements were undertaken in major paddy growing regions of the country under different rice environs for the whole cropping period in 1991.

Consequently, measurements of physiochemical parameters of atmospheric chemical composition and aerosol loadings at three different environments (Delhi, Pune and Darjeeling) are in progress to improve our understanding of the anthropogenic processes of atmospheric pollution, apart from the dynamics of atmospheric composition.

Reconstruction of past climate

The project is aimed to focus on the late Quaternary evolution and the palaeoenvironmental changes trend history of the Lower Narmada basin during the late Quaternary period. Based on the detailed geomorphic, sedimentological and stratigraphical studies, it has been established that the Narmada basin in Gujarat is a reactivated sedimentary basin, where interactions between sedimentary processes, tectonics, and climate and sea-level changes have influenced the nature of sediments.

The Birbal Sahni Institute of Palaeobotany (BSIP) has been exploring plant fossils that are reliable marks of plant climates. The palaeo-signals can be explored to decipher plants and possibly to predict future climatic changes. The BSIP has undertaken and completed studies on the causes and effects of deterioration of forest cover during the Holocene with particular emphasis of mangrove vegetation and Shola forests. Pollen analysis from lake sediments have revealed that around 3,000 B.C., the Eastern Himalayas experienced warm temperate climates, and during 1,000 B.C., it turned more humid, before changing to the climate we experience today. The institute has also prepared a master tree ring chronology of C*edrus deodara* and data obtained can be used to infer climate change/ variations, particularly drought cycles, during the past centuries.

The Indian Institute of Geo-magnetism (IIG) has correlated short-term weather changes with solar activity and geomagnetic field variations in the Indian region. This suggests that part geomagnetic field and climate should also be correlated. Variations of temperatures in the scale of a 100 to a 1000 years are being studied.

Climate variability and change

India's climate is dominated by the summer monsoon, which shows spatial, interannual and intra-seasonal variability. Climate variability has tremendous impact on agricultural production and water availability. Recognizing the role of land, atmosphere and oceanic processes in modulating the monsoon variability, a multi-disciplinary, decade-long Indian Climate Research Program (ICRP) has been evolved to study the climate variability and climate change issues in the Indian context. The ICRP envisages land-ocean atmosphere field experiments, the analysis of available past data sets on climate and agriculture, and climate modelling.

A number of research projects were supported to implement the inter-disciplinary and multi-institutional coordinated subprograms of the ICRP. The available land-based, ocean-based and space-based data sets are being analyzed towards improving our understanding of the monsoon variability in different socioeconomic sectors. Field experiments were conducted to validate the crop simulation models in different agro-climatic conditions. Also methane and NO_2 emissions were monitored under different ecosystems. Different global, regional and mesoscale models are being run to predict monsoon systems. In order to understand the regional and locally predominant variability, several processes-oriented field campaigns have also been organized.

Studies related to the physics and dynamics of monsoons, land-ocean-atmosphere coupled system, and indigenous development of technology for atmospheric science application, are being supported under MONTCLIM programme. In order to study the effect of weather and climate in tropics, efforts are being made to improve parameterization of land-ocean-atmospheric processes though the AOGCMs. Agrometeorological studies related to crop-weather relationships are also being sponsored under the MONTCLIM.

An organized Indian climatic research with a collaborative multi-institutional approach was begun as early as 1970s, with the launch of the Indian-Soviet monsoon experiment (ISMEX, 1973). During the summer months, six research vessels (four from the USSR and two from India) obtained meteorological and oceanographic measurements over the Arabian Sea, for the equatorial region and southern Indian Ocean. With the help of data, important insights into the onset of the monsoon, active and break of monsoon periods and oceanographic phenomenon were deduced.

In 1977, the Monsoon-77 experiment was organized to collect surface and upper air observations over the vast oceanic areas surrounding the Indian subcontinent for unraveling the peculiarities of monsoon circulation. It was executed as a forerunner of the experiment on sub-regional scale—Monsoon Experiment (MONEX) run as a subprogramme of the First Global GARP Experiment (FGGE). It was jointly conducted by India and the USSR for an intensive study on different scales for monsoon disturbances and for numerical simulations of the general atmospheric and ocean circulation in the monsoon regime. The routine observational programme over India was augmented during MONEX by arranging additional upper air observations over Bay of Bengal and Arabian Sea during the monsoon months, and by arranging increased radio-sonde flights from 16 existing upper air observational stations. MONEX was conducted over the oceanic regions near India with an objective to understand the ocean energy and its influence on different phases of monsoon. MONEX provided a comprehensive data set from a large area around India, where surface and upper air networks were augmented to meet the requirements. The upper air network was either augmented or newly established at nine observatories for radio-sonde observation in the existing network. In addition, upper air observations were also established at eight more stations for the purpose of MONEX; three surface observatories were also established. Efforts were also made to collect observations from commercial ships. Advantage was also taken of the observing network of FGGE with a fleet of about 20 ships. Upper air observations were also managed from these ships, along with deploying three more research ships in the Arabian Sea to meet MONEX requirements.

Hydrographic observations on board the Indian research vessel were made in a selected area of four squares in the east central Arabian Sea in relation to different phases (pre-monsoon, onset and post-onset) of the monsoon over the study area.

Stabilized platforms were provided to ships for making wind observations. MONEX provided enough data to establish the structure of the monsoon onset vortex.

During the 1990s, the Monsoon Trough Boundary Layer Experiment (MONTBLEX) was conducted during the monsoon months at four stations along the monsoon trough to understand the boundary layer behaviour during active and break phases. A huge data bank was generated for further utilization and model validations.

The late 1990s witnessed the grand Indian Ocean Experiment (INDOEX). INDOEX was a focused field experiment in the Indian Ocean with international participation from the developed world and other Asian countries. A three-month intensive field phase (IFP) was made with research aircraft, ship cruises and observations on the land surface. With almost the similar objectives as INDOEX, the Bay of Bengal Monsoon Experiment (BOBMEX) was conducted during 1999. BOBMEX particularly focussed on the intra-seasonal variability of organized convection in the atmosphere, and on the role played by ocean-atmosphere interactions in monsoon variability. Special observational platforms like deep-water meteorology-oceanography buoys, research ships, weather radars and satellites were used, together with conventional meteorological observatories to collect data on the variability of the monsoon and ocean-atmosphere system.

To understand the role of land surface and the model validation, the Land Surface Process Experiment (LASPEX) was carried out at five stations during 1997-1998 in the western Indian region. The major objective was the development of the Land Surface Model and its validation. Other major objective was inclined to Agricultural Meteorology modelling. The analysis of the LASPEX data set observed the double mixing of line structure developed during the monsoon at Anand and no gradient in the surface sensible heat flux within the LASPEX area.

A multi-institutional and multi-technique field experiment namely, the Arabian Sea Monsoon Experiment (ARMEX), has been designed under the ICRP since 2002, and is planned for execution in two phases. The main purpose of this experiment is to study offshore trough and vortex that play important roles in modulating monsoon activity over the west coast of India.

A two-dimensional interactive chemical model of the lower and middle atmosphere has been developed to study the atmospheric chemistry-climate interactions. The radiative forcing due to the growth of GHG due to human activities for the past three decades has been simulated. The ozone over the Indian Ocean is marked by significantly low values of ozone (10-20 ppb), followed by an increasing trend in the mid-troposphere and a steep gradient near the tropopause.

The Cloud Physics Laboratory in Pune University is presently a unique facility which carries out cloud studies in similar conditions in the atmosphere. The availability of such a facility for cloud-related research would be of paramount interest to physicists in the relevant field.

Other than these major efforts, many small scale projects have been and are being carried out. Some are also proposed in the near future to better understand the Indian weather and climate. For example, to understand the nature of coupled ocean-atmosphere system, an experiment has been executed over Indian oceanic region. The focus of research was the Bay of Bengal. The experiment has given insights into tropical convection. The results will have a major impact on our understanding of the coupling of the monsoons to the warm oceans and modelling of climate.

Under the focus of upcoming major programmes for research related to oceans; under the ARGO project, 150 floats have to be deployed in the Indian oceans between 2002-2007. A set of 12 floats have already been deployed. The temperature and salinity profiles are expected to improve the understanding of the oceanic processes and contribute to an improved prediction of climate variability.

The management of natural resources like soil and water is being carried out at eight central research institutes and two project directorates, three national research centres and 15 all-India coordinated research projects of ICAR.

Realizing the importance of environmental information, the Government of India, established the Environmental Information System (ENVIS) as a planned programme in December 1982. ENVIS is a decentralized system with a network of distributed subject-oriented centres ensuring the integration of national efforts in environmental information collection, collation, storage, retrieval and dissemination to all concerned (*http://www.envis..nic.in*). The ENVIS centres have been set up in different organizations/establishments in the country for assessing the environment for pollution control, toxic chemicals, central and offshore ecology. Besides collecting data, ENVIS supports environmentally sound and appropriate technology, bio-degradation of wastes and environment management research. The ENVIS focal point responded to 363 queries and the ENVIS centres over 19,694 queries. The major subject areas on which the queries were responded to pertain to laws, waste management, Coastal Regulation Zones (CRZ), environmental education and awareness, air and water pollution, wetlands, etc.

The ENVIS Focal Point implements the World Bank assisted Environmental Management Capacity Building Technical Assistance Project (EMCBTAP), which aims to strengthen the ENVIS scheme of the ministry. The ENVIS sub-component of the EMCBTA Project is slated for a period of 18 months from January 2002 to June, 2003. The project aims at broadening the ambit of ENVIS to include varying subject areas, and status of information/data pertaining to environment, and has been achieved through the participation of academic institutions, organizations, state governments and NGOs. The participating institutions, called ENVIS-Nodes have been assigned specific subject areas in the field of environment and are responsible for the collection, the collation and dissemination of relevant information through the web.

A portal on the environmental information system at http://www.envis.nic.in has been developed under the EMCBTA Project. It would act as a mother portal for all the 80 operative ENVIS centres and nodes, as well as 16 other nodes planned. The portal would act as a catalyst for inter-nodal interaction and information on seven broad categories of subjects related to the environment, under which the centres and nodes have been classified. The websites of the ENVIS centres and nodes can also be directly accessed from the home page of the portal.

In addition, various programmes for future needs like biomass energy, coal-bed methane recovery for commercial usage, energy efficient technology development, improvement of transport systems, small-scale hydro-electric power stations, and development of high-rate bio-methanation processes as a means of reducing GHG emissions are already being conducted or proposed.

Climate modelling research

Using various established climate models from the global front, different organizations are simulating the climate for India, with special attention to the Indian summer monsoon. GCMs from Laboratoire de Meteorologie Dynamique (LMD), Florida State University (FSU), ECMRWF, Center for Ocean, Land and Atmosphere (COLA), NCMRWF, and many more are being taken from the sources and are in the main front of global climate simulations in India. Regional models like the MM5, RegCM3 and Eta Model, are the forerunners in the regional climate simulations, with inputs from various GCMs.

For generating the past climate, a few statistics-based palaeo-climatological models are also in the forefront. Studies on the intra-seasonal and interannual variability of the monsoon, role of moist processes and orography in the GCM, and simulation of the monsoon. The results of these all the simulations are available to user groups for various scientific and practical requirements.

Agricultural meteorological modelling for Indian crop system with various models is the most accepted research method in India. Institutions like Indian Agriculture Research Institute, NCMRWF and various university-level research departments are carrying out such simulations. Through extension programmes like the Agro-Advisory Services of DST, the output information is transferred directly to the practical level, to farmers. The results are found to be encouraging at the farm level.

Field experiments were carried out at Palampur to generate all the relevant data on various crop parameters required for calibration of CERES-rice and wheat models. The models were validated using the observed data from the field experiments. The results indicated that the development stages are well simulated and grain yields are satisfactory. The validated models were used to simulate the effect of various management practices over a number of years on the yields of rice and wheat varieties.

At Anand, field experiments were undertaken during 1999-2000 and 2001-2002 wheat-growing periods. Crop, soil and micrometeorological data were used to estimate the land surface parameters. The radiation budget, sensible heat flux, latent heat flux, soil heat fluxes at different phenophases of the wheat crop were also computed. Initiated experiments of validate a COTTAM (cotton crop growth and yield simulation) model under Punjab and the plantation cropping system at Thiruvananthapuram.

A comprehensive programme on Indian Ocean Dynamics and Modelling (INDOMOD) was also launched during the Ninth Five-Year Plan, to develop a variety of wide-range coupled ocean-atmosphere models for application of the monsoon variability studies and ocean state forecast. The premier participating institutes in the INDOMOD are IISc, Bangalore; Centre for Mathematical Modelling and Computer Application Studies, Bangalore; IIT, Delhi and Indian Institute of Tropical Meteorology (IITM), Pune. The modelling activity will also be continued during the Tenth Plan period in a much more focused way, including the validation of models with *in-situ* data. Using the ship of opportunities, 70 drifting buoys were deployed for the acquisition of surface met-ocean parameters in real-time, using CLS ARGOS data transmission. For understanding upper ocean variability of heat content in the Indian ocean, XBT surveys in three shipping routes: (a) Chennai- Port-Blair-Kolkata; (b) Chennai-Singapore; (c) Mumbai-Mauritius are being carried.

In addition, there is a suite of algorithms/models for retrieval of ocean atmospheric parameters from Indian and foreign satellites under the department's project Satellite Coastal Oceanographic research (SATCORE) executed by the SAC, Ahmedabad. During 2001-2002 a pilot study was conducted on an experimental ocean state forecast, based on the models developed under SATCORE and INDOMOD projects for dissemination of four parameters in the Northern Indian ocean, viz. sea surface winds, sea surface temperatures, surface waves and mixed layer depth. These models and multidisciplinary data, currently available at INCOIS, Hyderabad, will also contribute to the various national projects implemented under the Indian Climate Research Programme viz., ASRMEX, INDOEX, which would require a great deal of data from upper ocean and surface meteorological parameters.

Satellite monitoring data for research

Satellite-based data has enriched and enhanced research on Indian forest cover, water resources, agriculture crops and climatic impacts on these resources. Ground truthing is used to validate and complement satellite data for a more robust analysis. For example, Indian remote-sensing satellite (IRS-1A/1B/1C & 1D) data relating to the entire Bhagirathi river watershed upstream of Devprayag on a 1:250,000 scale; for the Gangotri glacier area in particular on a 1:50,000 scale for the years 1997, 1998, 1999, 2000, 2001 and 2002; and pertaining to the peak accumulation and ablation period of each year, have been visually interpreted for snow cover assessment and mapping. The temporal monitoring of the variations in spatial extent of snow cover have also been statistically tabulated and graphically plotted. This has enabled monitoring the variations in snow cover in the entire Bhagirathi river watershed upstream of Devprayag and also in Gangotri sub-watershed in particular during the past decade or more.

The integration of satellite-derived information with collateral data has enabled monitoring the fluctuations in the position of the snout of the Gangotri glacier during the last decade and this in turn, has enabled monitoring the rate of retreat of the snout in recent times with greater accuracy. A digital analysis of topographic information has enabled the generation of the digital elevation model for the Gangotri glacier area as viewed from different visible angles. This has been prepared through the contours of the Gangotri glacier area by using the ARC/INFO GIS package.

Climate change-related impacts, vulnerability and adaptation research

India has reasons to be concerned with climate change. The vast population depends on climate-sensitive sectors like agriculture and forestry for livelihood. The adverse impact on water availability due to the recession of glaciers, decrease in rainfall and increased flooding in certain pockets would threaten food security, cause die-back of natural ecosystems including species that sustain the livelihood of rural households, and adversely impact the coastal system due to sea-level rise and extreme events. Apart from this, the achievement of vital national development goals related to other systems, such as habitats, health, energy demand, and infrastructure investments, would, be adversely affected.

Preliminary research has been initiated on vulnerability assessment due to climate change on various socioeconomic sectors and natural ecosystems in India during the preparation of India's Initial National Communication to the UNFCCC. Indian climate change scenarios at the sub-regional level were developed to estimate impacts on ecological and socioeconomic systems. This document represents the extant scientific capacity and consolidates the contemporary literature, besides shedding light on the vulnerability of different sectors and regions of the country to climate change, the need for devising adaptation responses, and demonstrates India's firm commitment to the objectives of the UNFCCC.

Many ministries of the Government of India have also initiated research on sectoral vulnerability assessment due to climate change. The MST, through the ICAR, has established an 'agro-meteorological data bank' for collecting, compiling and archiving various types of agro-meteorological data and has developed a website to access the data. Coordinated field experimental data available with the IMD is being analyzed to develop crop-weather relationship models to study climate change impacts on Indian agriculture. Studies have also been initiated on micro-regional (district as unit) rainfall variability and its influence on crop production in eastern Uttar Pradesh and plains of Bihar.

Many case studies have also been conducted, such as habitat diversity patterns of rarity in the terrestrial vegetation of North-Eastern Uttar Pradesh; species diversity in the Central Himalayas, patterns and relationships with ecosystem characters; seed characteristics, regeneration and growth improvement of deciduous trees of the Central Himalayas; biodiversity in response to disturbance gradient in the forest of Kumaon Himalayas.

In a project, during the course of exploration, more than 226 species of fern and fern-allies have been collected so far from Kumaon region and it has been observed that 52 species are under threat mainly due to habitat destruction and climatic changes. Out of these, 12 taxa are endangered.

GHG abatement research

This component has two prominent components. The first is the economic and environmental modelling based research for estimating future emissions, and alternate policy assessments to assist India in international negotiations. IIM Ahmedabad, The Energy and Resources Institute, Indira Gandhi Institute for Development Research, Jadavpur University, and National Chemical Laboratory, are some of the forerunners. These institutions employ many internationally used top-down and bottom-up models, such as Second Generation Model, Edmonds-Barns-Reilly model, MARKAL family of models, and Asia Pacific Integrated Model (AIM) family. This work promotes international collaboration among eminent Indian and foreign research institutes and researchers considerably. Indian researchers have been published in international journals and many prominent researchers have also contributed significantly to the IPCC assessments and reports since the last decade.

The second component covers the development of technologies for energy efficiency improvement, renewable energy, and sustainable development, thus in turn promoting GHG emission abatement. These encompass wide scientific and engineering disciplines. The IITs, CSIR laboratories and the IISc are at the forefront of this research. Some examples include efficient lighting appliances, wind turbines from low wind speeds with accelerating nozzles for irrigation and electric power generation, battery operated city cars, 4-stroke engines for two- and three-wheelers, efficient stand-alone microhydel-based power generation, solar power reliability and output enhancement, biofuels, waste to energy, coal-bed methane, non-coking coal beneficiation, ash utilization, multi stage hydrogenation technology for converting coal to oil, fuel cell technology, production of fuels and chemicals from methane and CO_2, in-situ infusion of fly ash with CO_2, soft coke technology, and energy efficient steel making technology.

SYSTEMATIC OBSERVATION NETWORKS

India has a long tradition of systematic observations, dating back centuries in different fields, including meteorology, geology, agriculture, sea level and land-survey, including mapping. Government departments, set up for specific purposes, have carried out these observations since the early 19 century. Observational networks have undergone changes according to evolving needs, and have also been modernized to a fair extent. Developments in space-based systems have contributed considerably to observational capabilities. India has also participated in international observational campaigns, both regionally and globally, to further the understanding of the climate and its variability.

Figure 4.2: Distribution of raingauge stations in India.

Atmospheric monitoring

There are 22 types of atmospheric monitoring networks that are operated and coordinated by the IMD (Table 4.1). This includes meteorological/ climatological, air pollution and other specialized observation of trace atmospheric constituents. Meteorological observations began in India as early as 1793, when the first observatory was established at Madras (now Chennai). The IMD formally set up in 1875, is the principal agency that monitors the weather and climate. IMD maintains 559 surface meteorological observatories (see Figure 4.2 for distribution of raingauge stations), and about 35 radio-sonde and 64 pilot balloon stations for monitoring the upper atmosphere. Specialized observations are made for agro-meteorological purposes at 219 stations and radiation parameters are monitored at 45 stations. There are about 70 observatories that monitor current weather conditions for aviation.

One of the automated surface observatories of the India metrological department measuring radiation, temperature, humidity, rainfall, wind direction and speed and transmitting this information on real time basis.

Although, severe weather events are monitored at all the weather stations, the monitoring and forecasting

Table 4.1: Atmospheric monitoring networks.

1	Surface observatories	559
2	Pilot balloon observatories	65
	a RS/RW observatories	34
	b Only RS observatories	1
3	Aviation current weather observatories	71
4	Aviation forecasting offices at national and international airports	19
5	Regional area forecast centre	1
6	Storm detecting radar stations	17
7	Cyclone detection radar stations	10
8	High-wind recording stations	4
9	Stations for receiving cloud pictures from satellites	
	a Low-resolution cloud pictures	7
	b High-resolution cloud pictures	1
	c INSAT-IB cloud pictures (SDUC stations)	20
	d APT Stations in Antarctica	1
	e AVHRR station	1
10	Data Collection Platforms through INSAT	100
11	Hydro-meteorological observatories	701
	a Non-departmental rain gauge stations	
	i Reporting	3540
	ii Non-reporting	5039
	b Non-departmental glaciological Observations (non-reporting)	
	i Snow gauges	21
	ii Ordinary rain gauges	10
	iii Seasonal snow poles	6
12	Agro-meteorological observatories	219
13	Evaporation stations	222
14	Evapotranspiration stations	39
15	Seismological observatories	58
16	Ozone monitoring	
	a Total ozone and Umkehr observatories	5
	b Ozone-sonde observatories	3
	c Surface ozone observatories	6
17	Radiation observatories	
	a Surface	45
	b Upper air	8
18	Atmospheric electricity observatories	4
19	(a) Background pollution observatories	10
	(b) Urban Climatological Units	2
	(c) Urban Climatological Observatories	13
20	Ships of the Indian voluntary observing fleet	203
21	Soil moisture recording stations	49
22	Dew-fall recording stations	80

Source: http://www.imd.ernet.in

of tropical cyclones is specially done through three Area Cyclone Warning Centres (Mumbai, Chennai, and Kolkata) and three cyclone warning centres (Ahmedabad, Vishakhapatnam and Bhubaneshwar), which issue warnings for tropical storms and other severe weather systems affecting Indian coasts.

Storm and cyclone detections radars are installed all along the coast and some key inland locations to observe and forewarn severe weather events, particularly tropical cyclones. The radar network is being upgraded by modern Doppler Radars, with enhanced observational capabilities, at many locations.

Data archival and exchange

The tremendous increase in the network of observatories resulted in the collection of a huge volume of data. The IMD has climatological records even for the period prior to 1875, when it formally came into existence. This data is digitized, quality controlled and land archived in electronic media at the National Data Centre, Pune. The current rate of archival is about three million records per year. At present, the total holding of data is about 9.7 billion records. They are supplied to universities, industry, research and planning organizations. The IMD prepared climatological tables and summaries/ atlases of surface and upper-air meteorological parameters and marine meteorological summaries. These climatological summaries and publications have many applications in agriculture, shipping, transport, water resources and industry.

The IMD has its own dedicated meteorological telecommunication network with the central hub at New Delhi. Under the WWW Global Telecommunication System, New Delhi functions as a Regional Telecommunication Hub (RTH) on the main telecommunication network. This centre was automated in early 1976, and is known as the National Meteorological Telecommunication Centre (NMTC), embracing the Regional Telecommunication Hub (RTH) New Delhi. Within India, the telecommunication facility is provided by a large network of communication links.

The website of IMD (*http://www.imd.ernet.in*), operational from 1 June, 2000, contains dynamically updated information on all-India weather and forecasts, special monsoon reports, satellite cloud pictures updated every three hours, Limited Area Model (LAM) generated products and prognostic charts, special weather warnings, tropical cyclone information and warnings, weekly and monthly rainfall distribution maps, earthquake reports, etc. It also contains a lot of static information, including temperature and rainfall normals over the country and a brief overview of the activities and services rendered by IMD.

Over the last three decades, the MST has successfully completed a few major research and data collection experiments through its autonomous body IITM, other allied institutions and foreign collaborations through several field experiments such as IIOE, ISMEX-73, MONSOON-77, MONEX-79, MONTBLEX, INDOEX, BOBMEX, and ARMEX. Along with these, the IITM undertakes regular oceanic expeditions on research vessels, Antarctic expeditions and field campaigns.

The IMD, in collaboration with the NPL plays an important role for climate change-related long-term data collection at the Indian Antarctic base-*Maitri*. Continuous surface meteorological observations for about 22 years are now available for Schirmacher Oasis with National Data Centre of IMD (NDC). Long-term environment-related GHG data is also available with NPL.

The IMD collects meteorological data over oceans by an establishment of cooperation fleet of voluntary observing ships (VOF) comprising merchant ships of Indian registry, some foreign merchant vessels and a few ships of the Indian Navy. These ships, while sailing on the high seas, function as floating observatories. Records of observations are passed on to the IMD for analysis and archival.

Another climate change-related data archival effort is at NPL *(www.npl-cgc.ernet.in)*, that holds a variety of data collected under different national and international programmes such as Indian Ocean Experiment (INDOEX), Asia Pacific Network for Global Change supported research projects. Another off-line data archival centre is emerging at IIM, Ahmedabad for the data generated during India's Initial National Communication Project *(www.natcomindia.org)*.

Satellite-based observations

Currently, several operational meteorological satellite systems are providing global and regional observations. The Indian Space Programme, initiated in the mid-1970s, selected meteorology and weather forecasting as one of the thrust areas. One of the earliest satellites 'Bhaskara' had a microwave payload SAMIR to study the atmosphere and ocean. The Indian National Satellite (INSAT) series was conceptualized as a multi-purpose geostationary satellite system for communications, meteorology, oceanography, and weather services. Table 4.2 provides information on the development and deployment of satellites in India.

Data, related to meteorology, obtained by INSAT is processed and disseminated by the INSAT meteorological data-processing system (IMDPS) of IMD. Information on upper winds, sea surface temperatures and precipitation index are regularly obtained at 0600H GMT. The 0300H GMT full disc infrared pictures are obtained as radio facsimiles for reception in the neighbouring countries and for national news network for weather reporting.

The INSAT 1 series launched in late 1980s carried a Very High Resolution Radiometer (VHRR) payload that operated in two spectral bands—visible (0.55-0.75 mm) and thermal infrared (10.5-12.5 mm). The INSAT system is designed to provide the following services:

- Round the clock surveillance of weather systems including severe weather events around the Indian region.
- Operational parameters for weather forecasting—cloud cover, cloud top temperature, sea surface temperature, snow cover cloud motion vector, out-going long-wave radiation, etc.
- Collection and transmission of meteorological, hydrological and oceanographic data from remote/inaccessible areas through Data Collection Platforms.
- Timely dissemination of warning of impending disasters such as cyclones through Cyclone Warning Dissemination Systems.
- Dissemination of meteorological information including processed images of weather systems through SDUCs.

Table 4.2: Information on development and deployment of Indian satellites.

Satellite	Launch Date	Achievements
Aryabhata	19.04.1975	First Indian satellite. Provided technological experience in building and operating a satellite system.
Bhaskara-I	07.06.1979	First experimental remote-sensing satellite. Carried TV and microwave cameras.
Bhaskara-II	20.11.1981	Second experimental remote-sensing satellite similar to Bhaskara-1.
Ariane Passenger Payload Experiment (APPLE)	19.06.1981	First experimental communication satellite. Provided experience in building and operating a three-axis stabilized communication satellite.
Rohini Technology Payload (RTP)	10.08.1979	Intended for measuring in-flight performance of first experimental flight of SLV-3, the first Indian launch vehicle. Could not be placed in orbit.
Rohini (RS-1)	18.07.1980	Used for measuring in-flight performance of second experimental launch of SLV-3.
Rohini (RS-D1)	31.05.1981	Used for conducting some remote-sensing technology studies using a landmark sensor payload.
Rohini (RS-D2)	17.04.1983	Identical to RS-D1. Launched by the second developmental launch of SLV-3.
Stretched Rohini Satellite Series (SROSS-1)	24.03.1987	Carried payload for launch vehicle performance monitoring and for Gamma Ray astronomy. Could not be placed in orbit.
Stretched Rohini Satellite Series (SROSS-2)	13.07.1988	Carried remote sensing payload of German space agency in addition to Gamma Ray astronomy payload. Could not be placed in orbit.
Stretched Rohini Satellite Series (SROSS-C)	20.05.1992	Launched by third developmental flight of ASLV. Carried Gamma Ray astronomy and aeronomy payload.
Stretched Rohini Satellite Series (SROSS-C2)	04.05.1994	Identical to SROSS-C. **Still in service.**
Indian National Satellite (INSAT-1A)	10.04.1982	First operational multi-purpose communication and meteorology satellite procured from US. Worked only for six months.
Indian National Satellite (INSAT-1B)	30.08.1983	Identical to INSAT-1A. Served for more than design life of seven years.
Indian National Satellite (INSAT-1C)	21.07.1988	Same as INSAT-1A. Served for only one and a half years.
Indian National Satellite (INSAT-1D)	12.06.1990	Identical to INSAT-1A. **Still in service.**
Indian National Satellite (INSAT-2A)	10.07.1992	First satellite in the second-generation Indian-built INSAT-2 series. Has enhanced capability than INSAT-1 series. **Still in service.**
Indian National Satellite (INSAT-2B)	23.07.1993	Second satellite in INSAT-2 series. Identical to INSAT-2A. **Still in service.**
Indian National Satellite (INSAT-2C)	07.12.1995	Has mobile satellite service, business communication and television outreach beyond Indian boundaries. **Still in service.**

Satellite	Launch Date	Achievements
Indian National Satellite (INSAT-2D)	04.06.1997	Same as INSAT-2C. Inoperable since 4 October, 1997 due to power bus anomaly.
INSAT-2E	03.04.1999	Multipurpose communication and meteorological satellite
Indian Remote Sensing Satellite (IRS-1A)	17.03.1988	First operational remote-sensing satellite.
Indian Remote Sensing Satellite (IRS-1B)	29.08.1991	Same as IRS-1A. **Still in service.**
Indian Remote Sensing Satellite (IRS-1E)	20.09.1993	Carried remote-sensing payloads. Could not be placed in orbit.
Indian Remote Sensing Satellite (IRS-P2)	15.10.1994	Carried remote-sensing payload.
Indian Remote Sensing Satellite (IRS-1C)	28.12.1995	Carries advanced remote-sensing cameras. **Still in service.**
Indian Remote Sensing Satellite (IRS-P3)	21.03.1996	Carries remote-sensing payload and an X-ray astronomy payload. **Still in service.**
Indian Remote Sensing Satellite (IRS-1D)	29.09.1997	Same as IRS-1C. **Still in service.**
Kalpana	2003	Exclusive meteorological satellite, VHRR, **Still in service.**

Source: http://www.isro.org/sat.htm

The INSAT 1 series consisted of four satellite missions with VHRR payload giving visible images with 2.75 km resolution and thermal data with 11 km resolution, with the capability to provide three hourly images and half-hourly images in sector scan mode.

The INSAT 2 series that followed was designed based on user feedback and consists of five satellites to ensure the continuity of services in an enhanced manner. INSAT 2A and 2B launched in 1992 and 1993 carried VHRR payload with improved resolution of l2 km in visible, and l8 km in thermal band. The imaging capability included three modes, viz. full frame, normal mode and sector mode of five minutes for the rapid coverage of severe weather systems.

INSAT 2E launched in 1999 carried an advanced VHRR payload operating in three channels – visible l (2 km), thermal and water vapour (8 kms.). The water vapour channel operating I 5.7-7.1 m is capable of giving water vapour distribution and flow patterns in the lower troposphere. Besides this, INSAT 2E also carries a CCD camera with three channels—visible, near infrared and short wave infrared with one km. resolution to map the vegetation cover.

Recently, METSAT, the first exclusive Indian Meteorological satellite in geostationary orbit, was successfully launched, and carrying advanced VHRR operating in visible, infrared and water vapour channel. INSAT 3A will have identical payloads as INSAT 2E; INSAT 3D planned in the future will carry an atmospheric sounder for temperature and water vapour profiles and split thermal channels for accurate sea surface temperature retrieval.

At present, repetitive and synoptic weather system observations over Indian oceans from geostationary orbit are available from the INSAT system. The INSAT-VHRR data is available in near real-time, at 32 meteorological data dissemination centres (MDDC) in various parts of the country. With the commissioning of direct satellite service for processed VHRR data, MDDC data can now be provided at any location in the country on a real-time and archived basis.

A centre for exchange of satellite data in the field of earth and atmospheric sciences has been established at IMD New Delhi as a part of Indo-US bilateral programme. Dedicated communication links have been established from this centre to the corresponding centre in NASA, US. The Indian scientists from different institutes are using data products available through this data centre for research activities.

A 100 meteorological data collection platforms (DCP) have been installed all over the country and at the Indian base in East Antarctica (Schirmacher Oasis-Maitri Station). The CWC and Snow and Avalanche Study Establishment (SASE) are also using INSAT facilities for real-time hydro-meteorological data collection in the Mahanadi and Chambal basins, respectively.

Measurements of trace constituents and air pollution monitoring

The Central Pollution Control Board (CPCB) initiated a nation-wide programme in 1984, called the National Ambient Air Quality Monitoring (NAAQM), with a network of 28 monitoring stations covering seven cities for air quality monitoring as an integral part of the air pollution control programme. Over the years, the number of stations has increased and presently, the network comprises 290 stations spread over 92 cities/towns distributed over 24 states and four Union Territories UTs (Figure 4.3).

Figure 4.3: National Ambient Air Quality Monitoring network.

Source: CPCB, Government of India.

In addition to the NAAQM programme, operated by CPCB, many state boards have set up their own Ambient Air Quality Monitoring (AAQM) programmes. Its objectives are to:

- Strengthen the existing air monitoring system with the adoption of state-of-the-art methodologies to monitor the air quality.
- Monitor the criteria pollutants depending on the locations.
- Determine present air quality status and trend.
- Provide background air quality data as needed for industrial sighting and town planning.
- Control and regulate pollution from industries and other sources to meet the air quality standards.

In addition to direct government controlled monitoring, the National Environmental Engineering Research Institute (NEERI) monitors ambient air quality in 30 stations covering 10 major cities. Major industries have also set up their own monitoring stations near their production units as part of the compliance of the consent conditions.

The pollutants monitored are Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2) and Suspended Particulate Matter (SPM), besides the meteorological parameters, like wind speed and direction, temperature and humidity. In addition to the three conventional parameters, NEERI monitors special parameters like Ammonia (NH_4), Hydrogen Sulphide (H_2S), Respirable Suspended Particulate Matter (RSPM) and Polyaromatic Hydrocarbons (PAH).

In another atmospheric observation initiative, the IMD established 10 stations in India as a part of World Meteorological Organization's (WMO) Global Atmospheric Watch (GAW, formerly known as Background Air Pollution Monitoring Network or BAPMoN). The Indian GAW network includes Allahabad, Jodhpur, Kodaikanal, Minicoy, Mohanbari, Nagpur, Portblair, Pune, Srinagar and Visakhapatnam. Atmospheric turbidity is measured using hand-held Volz's Sunphotometers at wavelength 500 nm at all the GAW stations. Total Suspended Particulate Matter (TSPM) is measured for varying periods at Jodhpur using a High Volume Air Sampler. Shower-wise wet only precipitation samples are collected at all the GAW stations using specially designed wooden precipitation collectors fitted with stainless steel or polyethylene funnel precipitation collectors. After each precipitation event, the collected water is transferred to a large storage bottle to obtain a monthly sample. Monthly mixed samples collected from these stations are sent to the National Chemical Laboratory, Pune, where these are analyzed for pH, conductivity, major cations (Ca, Mg, Na, K, NH_4^+) and major anions (SO_4^{2-}, NO_3^-, Cl^-).

Marine observations

Climate variability in the recent past has caused a great deal of impact on the weather pattern, resulting in droughts and extreme heat events in various countries of the Indian Ocean. Climate predictability is an imperative need for India that is heavily dependent on monsoons for its economy. Although the oceans play an important role in the climate change, the symbiotic connection between ocean and atmosphere, particularly in terms of exchange of heat and mass is not yet well understood. This could be due to a lack of systematic observational network in the seas around India.

The history of sea-level measurement in India goes back to the period 1806-1827 when the first tidal

Ocean measurements being carried out in the Arabian Sea.

observations work was undertaken by James Kyd at the Khidirpur (Kidderpore) docks, Hooghly River and continued at Sagar Island during 1828-1829. In 1877, the Government of India entrusted the responsibilities of carrying out systematic tidal observations to the Survey of India to determine mean sea level for establishing the data for the Vertical Control of India. Since then, numerous tidal stations have been established. At present, there are 22 functional tidal stations under the technical control of the Survey of India.

The department of the Ocean development has instituted national facilities for Oceanographic research which include Ocean research vessels like Sagar Kanya, Sagar Sampata, Sagar Purvi, Sagar Paschimi and some data buoy vessels and new technology demonstration vessels.

Recognizing the importance of information and knowledge of the seas around India, the DoD formulated an integrated programme called 'Ocean Observation and Information Services (OOIS)' for implementation during the Ninth Five-Year Plan (1997-2002). It comprised the integration of ongoing projects and launching of new ones implementing the OOIS programme. OOIS consisted of four components, viz., Ocean Observations, Information Services, Modelling and Satellite research projects. OOIS aims at: (a) development of wide range ocean-atmospheric and coastal models; (b) generation of algorithms for retrieval of satellite parameters; (c) augmentation of ocean observations including *in-situ* and satellite measurements; and (d) operationalization of ocean advisory services.

An ocean research vessel *Sagar Kanya* of the Department of Ocean Development.

Box 4.1: Oceanographic Infrastructure – National Facility

- ORV Sagar Kanya
- FORV Sagar Sampada
- CRV Sagar Purvi
- CRV Sagar Paschimi
- New data buoy vessel - for deployment, operational and maintenance of ocean observational networks such as moored ocean buoys, ARGO, Drifting buoys, XBTs, current meter array and other oceanographic research activities.
- New technology demonstration vessel

In view of the contribution of data generated through observational platforms for weather/ climate forecasting and other coastal development activities, it is proposed to strengthen and augment the observational network during the Tenth Five-Year Plan (2002-2007) by deployment of a variety of state-of-the-art technology buoys and floats. Several national agencies, such as, the National Institute of Oceanography (NIO) at Goa, the National Institute of Ocean Technology (NIOT) at Chennai, and the Survey of India at Dehradun have been involved in the generation of data pertaining to coastal and open seas of India. Towards collating and archival of the data and effective dissemination of information to the end users through a single window, a dedicated centre called the Indian National Centre for Ocean Information Services (INCOIS) was established at Hyderabad in February 1999. Accomplishments of this scheme are:

Ocean Observing Systems

The ocean observations, both *in-situ* and satellite measurements, play a vital role in understanding the ocean atmospheric processed. Systematic time-series surface metrological and oceanographic observations are essential primarily to improve oceanographic services and predictive capability of short- and long-term climate changes. The time series observation data on waves, wind, currents, air temperature, pressure and others are required for carrying out basic research and developmental activities in the coastal/ ocean areas and to study ocean processes. Recognizing the importance of these measurements, the DoD has proposed to augment the observational network during the Tenth Five-Year Plan by deployment of a set of state-of-the-art profiling floats and moored ocean data buoys.

Moored Ocean Data Buoy Programme

The primary objectives are to support national, regional and international programmes relating to ocean sciences and technology by providing real-time and archived data and related information and to provide real-time data for programmes relating to the prediction of movement of cyclones and consequent storm surges that are devastating in nature.

During the Ninth Five-Year Plan, the DoD established a 12-ocean buoy network in the areas around India, with partial financial assistance from the Norwegian Agency for Development Cooperation (NORAD), Norway. The data buoys are equipped to record the data on atmospheric temperature, humidity, pressure, sea surface temperature, and salinity and wave parameters through their sensors. They are transmitted to the International Maritime Satellite (IMMARSAT) and received at NIOT. Data is regularly disseminated to users like IMD for weather predictions. The other user groups include, Climate Research Group in Department of Science and Technology, the IISc, the Navy, and Ports. The NIOT is currently operating 14 moorings, out of which 12 are providing real-time data. In order to attain self-reliance, the NIOT is under an advanced stage of indigenous production of these data buoys, including the critical central processing unit, and the satellite transmitter and transceiver for INSAT, which has been jointly developed by NIOT and the SAC, Ahmedabad.

Indian Array for Real-time Geotropic Oceanography (ARGO) Project

The International ARGO project envisages the deployment of 3,000 profiling floats in the global ocean at approximately 3^0x3^0 (300 km x 300 km) resolution. About 20 countries including India, have committed resources to the project. The floats in ARGO will provide temperature and salinity data over the entire world's ocean at 10-day intervals. These floats are designed to dive up to 2,000 m depth to make measurements and transmit the data through satellite to ground stations, when they reappear. Each float is capable of making 200 profiles over a period of five years.

Under this programme, 450 ARGO floats are to be deployed in the Indian Ocean region. India holds a major share of such buoys in the Indian Ocean region, thus acquiring a leadership in the regional climate programme. The DoD has made a commitment for the deployment of about 150 in the northern Indian Ocean north of 10^o South over a period of five years (2002-2007), of which 12 have already been deployed. For the first time in the Indian Ocean, India conducted a 3-ARGO float mission with 10 days, five days, and 10 & five-day cycles to capture the inter-annual variability in the region. Data from these floats is being received and made available on the website for users after the real-time quality checks. The Indian National Centre for Ocean Information Services, the National Institute of Ocean Technology and the IISc are the other institutions involved in this programme.

In the long run, the ARGO data would help to greatly improve our knowledge of scientific problems such as the interaction of atmosphere and ocean on interannual time scales, as well as providing a highly useful set of measurements that will be relevant to more practical problems associated with shipping, fisheries and environmental assessment applications. This will also contribute to various national projects being undertaken by India, through the Indian Climate Research Program (ICRP). These temperature and salinity profiles are expected to improve our understanding of the oceanic processes and contribute to improved prediction of climate variability.

Data from the global array of profiling floats would be put on the GTS immediately to enable its use in operational forecasting. Delayed mode data, after detailed quality control checks by the ARGO data centres, would be available within a few months via the Internet. One-year time series data collected from the Canadian Float deployed by India were analyzed and developed to decide the ARGO Float design for the Indian Ocean region.

A website for the India ARGO Programme with Web GIS and query facilities and for coordination of ARGO float deployment in the Indian Ocean was set up. Data from about a 100 floats (about 2,600 temperature and salinity profiles) deployed by various countries in the Indian Ocean is available on the INCOIS website for the scientific community. Data from 600 floats have also been archived. Under a joint project of INCOIS and CAO/ IISc, the hydrographic structure of western Arabian Sea was studied, using the data from ARGO floats in the region. A software package for on-line real-time quality control of ARGO data, incorporating 21 quality checks approved by the International Agro Science Team was developed.

There are three autonomous bodies of the DoD viz., the National Institute of Ocean Technology, Chennai; the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad and the National Centre for Antarctic and Ocean Research (NCAOR), Goa which are primarily responsible for deployment, operation and maintenance of ocean observation platforms and ships for promoting the ocean observations. In addition, the National Institute of Oceanography, Goa and the Survey of India, Dehradun had executed projects for acquisition of oceanographic data, under the Ocean Observing System of the DoD.

Considering the importance of the data and its utility to various national programmes, the DoD has proposed to strengthen the observational network during the Tenth Plan by deployment of state-of-the-art technology ARGO profiling floats in the Indian ocean north of 10^0 south for real-time collection of temperature and salinity data up to a depth of 2000 m. A set of 10 ARGO floats out of the proposed 150 floats has already been deployed in the Bay of Bengal. The moored data buoy network will be increased to 40. Under the sea-level programme, 10 Float type digital tide gauge stations were established in major ports of India for systematic, accurate and long time measurements of sea level.

Indian National Centre for Ocean Information Services (INCOIS)

In order to coordinate the various projects and to generate and supply data products effectively to the users through a single window, an autonomous body known as the Indian National Centre for Ocean Information Services (INCOIS) was established in 1999, at Hyderabad. The mandate of INCOIS is to synthesize, generate, promote, provide and coordinate various activities for ocean science observations, information and advisory services. Further, synergy and knowledge networking with centres of excellence in ocean atmospheric sciences, space application centres and information technology as well as translating the scientific knowledge into useful products are primary goals of INCOIS. This centre is marching ahead with a mission to provide the best possible ocean information and advisory services to society, industry, government agencies and scientific community research. Within a short span of its existence, the INCOIS has been recognized as an institution focusing on providing advances in space and ocean sciences to help the common man. Further, the initiatives taken by INCOIS during the last two years with respect to the International ARGO programme and the Global Ocean Observing System have enabled India to gain a significant niche in the global scenario. INCOIS has also been recognized as the Regional ARGO data centre for Indian Ocean.

Terrestrial observations

Cryospheric observations

A systematic study of glaciers was begun by the Geological Survey of India (GSI) during 1907 to 1910, as part of an international programme to study glaciers. In 1974, it established the Glaciology Division for northern region, with its headquarters at Lucknow and the Eastern Region Division established at Kolkata in 1979.

The GSI carried out glaciological studies in Jammu and Kashmir (Neh-Nar, 1974-1984; Harmuk and Rulung); Himachal Pradesh (Gara, 1973-1983; Gor Garang, 1975-1985; Shaune Garang; 1981-1991); Uttar Pradesh (Tipra Bamak, 1980-1988; Dunagiri, 1984-1992); and Sikkim (Zemu and Changme Khangpu glaciers). It also carried out snow cover assessment of Beas basis, Dhauliganga valley, and Sind Valley. The GSI has thus completed the first generation glacier inventory of UP, HP, J&K and Sikkim. They have largely confined their study to mass balance, glacier recession, suspended sediment transfer and geomorphological studies.

The Survey of India (SOI), the oldest scientific department of the Government of India, set up in 1767, is the national survey and mapping organization of the country. The most significant contribution of SOI in the study of glaciers, is the accurate demarcation of all glaciers on topographical maps that can provide a vital data source for glaciological research.

The IMD established the glaciology Study Research Unit in Hydromet Directorate in 1972. This unit has been participating in glaciological expedition organized by the GSI and the DST. The unit was established for the: (a) determination of the natural water balance of various river catchment areas for better planning and management of the country's water resources; (b) snow melt run-off and other hydrological forecasts; (c) reservoir regulation; (d) better understanding of climatology of the Himalaya; and (e) basic research of seasonal snow cover and related phenomena. The IMD has established observing stations over the Himalayan region to monitor weather parameters over glaciers.

The Snow and Avalanche Study Establishment (SASE), a defense research organisation has been working in the field of snow avalanches since 1969. The emphasis has been the mitigation of snow avalanche threat by various active and passive methods. Avalanche forecasting and avalanche control measures form the front-line research areas of this establishment. The basic research in snow physics, snow mechanics and snow hydrology naturally followed in pursuit of the solutions to problems related to snow avalanches. SASE has established about 30 observatories in western Himalayan region, which are very close to the glacier environment. The data collected at these observatories mostly pertains to weather, snow and avalanches. In addition, a chain of 10 Automatic Weather Stations (AWS) has been established at different places in the western Himalayan region. Of these, two have been installed right on a glacier.

In addition, these several other academic and research institutions, like the Wadia Institute of Himalayan Geology (WIHG), Physical Research Laboratory (PRL) and the Jawaharlal Nehru University (JNU) have actively taken part in studying of the Himalayan glaciers.

Satellite-based observations of the glaciers and their mass balance characteristics are also being carried out regularly by the SAC.

Ecosystems

India by virtue of its varied topography, climate and habitats, is very rich in biodiversity resources right from cold deserts to the tropical littoral forests. It is also rich in its folk and traditional knowledge of properties and uses of these resources. Biodiversity resources are valued directly, such as food for humans, fodder for animals, energy sources as fuel, nutrients like leaf manure and structural materials like pharmaceuticals, fibre, fragrances, flavours, dyes and other materials of special interest.

A record of India's plant wealth indicates that there are approximately 17,500 species of angiosperms, 48 species of gymnosperms, 1,200 species of ferns, 6,500 species of algae, 14,500 species of fungi, 2,500 species of lichens, 845 species of liverworts and 1,980 species of mosses. Several organizations are involved in the observational and research aspects of the flora and fauna of the country, as also the different ecosystems.

The FSI, an organization under the MoEF, has been undertaking assessment of forest resources in the country since 1965. As per its current mandate, the FSI has to assess the forest cover of the country in a two-year cycle, which is published regularly in the form of 'State of Forest Report' (SFR). The latest SFR 2001 reports the forest cover of the whole country at a 1:50,000 km scale, using a combination of remote sensing satellite data and field survey. Study improvements have resulted in a complete picture of the extent of forest and tree cover in India. The present assessment shows that forest covers (20.55 per cent) and tree cover (2.48 per cent) constitute a healthy 23.03 per cent of the country's geographical area. For the first time, an error matrix has been generated by comparing the classified forest cover with the actual forest cover on the ground, at 3,680 locations spread throughout the country to arrive at the accuracy of forest cover classification. The present assessment shows that mangrove cover in the country occupies an area of 4,482 sq. km of which 2,859 sq. km is dense mangrove.

Many research institutions and Agricultural Universities under the ICAR are engaged in data collection and research in the agriculture sector. The agronomy division of the ICAR, over the past 50-60 years, has gathered soil parameters for agricultural resource management. Agriculture-related weather data and grain-wise agricultural yield data are collected at the local level at evenly distributed sites all over the India.

Hydrological observations

The Central Water Commission (CWC) under the MWR, operates a national network of about 877 hydrological observation stations. The data observed at field units is processed at various levels and archived. The CWC is also imparting training to various research institutions, universities, central and state pollution control boards for the systematic collection of river water samples.

The Central Ground Water Board (CGWB), another institution under the MWR, monitors the ground water levels from a network of 14,995 stations (mostly dug wells) distributed evenly throughout the country. Dug wells are being gradually replaced by Piezometers for water-level monitoring. Measurements of water levels are done four times during the year in the months of January, April/ May, August and November. The ground water samples are collected during April/May for analyses of chemical changes. The generated data is used to prepare maps of ground water-level depths, water-level contours and changes in water-levels during different time periods. The data is also used to prepare long-term changes trends in water levels. The CGWB has categorized the Indian subcontinent into 12 basins. At the basin level, several parameters are being monitored and are available with the CWC for various national research needs (Table 4.3).

Conclusion

India has invested heavily in scientific infrastructure with the view that a strong science and technical base is key to industrial development and self-reliance. This included setting up independent institutes of higher education in science and engineering, as well as a complex of national laboratories under the umbrella of the CSIR, the ICAR and other autonomous research institutes of excellence under various ministries and departments. India now has

Table 4.3: Basin-wise hydrological and sediment observation.

States/Regions	G*	GD*	GDS*	GDW*	GDSW*	Total
East-coast rivers of Andhra Pradesh	24	59	0	24	50	**157**
Brahmaputra basin	64	27	14	0	12	**117**
East-coast rivers of Tamil Nadu	0	3	0	13	14	**30**
East-coast -rivers of Orissa and West Bengal	27	15	0	1	24	**67**
Ganga basin, Damodar basin and Kangsabati	92	110	6	29	89	**326**
Indus basin	1	15	9	0	0	**25**
West-coast rivers of Kerala	0	0	0	3	16	**19**
Rivers of Meghalaya	0	4	0	0	0	**4**
West-coast rivers of Gujarat	18	25	0	9	32	**84**
Rivers of Mizoram and Manipur	5	5	1	0	0	**11**
Barak and other rivers of Tripura	4	11	11	0	0	**26**
West-coast rivers of Maharashtra, Goa and Karnataka	1	7	0	1	2	**11**
Total	236	281	41	80	239	**877**

*G=Gauge, GD= Gauge Discharge, GDS=Gauge Discharge and Silt, GDW= Gauge Discharge and Water Quality, GDSW=Gauge Discharge, Silt and Water Quality.

one of the largest scientific manpower in the world. This serves as a backdrop for understanding the potential of Indian science to address climate change research and assessment. Collaborative activities among these groups are rarely catalyzed by institutional or programmatic structures. Of late, there have been some efforts by the DST to coordinate climate research through its Indian Climate Research Programme (ICRP, launched in 1996), which has successfully mounted observational efforts (BOBMEX, ARMEX) to understand the Indian south-west monsoon variability. New programmes to bring together research groups to solve common problems have also been initiated by the MoEF. There is however, a strong need to integrate the research efforts to focus on climate change issues of relevance for the region.

Chapter 5

Education Training and Public Awareness

Education, Training and Public Awareness

Chapter 5

Environmental protection and sustainable development are India's key national priorities. This commitment is reflected through outreach and education efforts undertaken by the government, civil society organizations, academic and research institutions, industry associations and the media. .

MINISTRY OF ENVIRONMENT AND FORESTS

The Ministry of Environment and Forests (MoEF) is the nodal agency for the subject of climate change in India. The MoEF has created various mechanisms for increasing public awareness and enhancing research in climate change by giving grants for wide-ranging research programmes and creating centres of excellence. These encompass issues related to environment as well as climate change. Some notable initiatives are as under:

Awareness generation

The first step towards meeting the challenges posed by climate change is to create awareness among civil society as well as policy-makers about its causes and potential consequences. The MoEF has instituted variety of measures, for information dissemination and outreach. The Government of India has a long-standing commitment and policies for dissemination of environmental information. The Environmental Information System (ENVIS) was instituted as a plan programme in December 1982. Since its inception, the focus of ENVIS has been on providing environmental information to decision makers, policy planners, scientists and engineers, research workers, and other stakeholders all over the country. (See Box 1).

Since environment is an all encompassing and multi-disciplinary subject, building a comprehensive information system on the environment necessitates

Box 5.1: ENVIS

This is a virtual system managed under the umbrella of the MoEF for archiving information and data on various environment-related activities including climate change. The website of this activity is www.envis.nic.in

The subjects covered include:

- Chemical waste and toxicology
- Ecology and ecosystems
- Flora and fauna
- Environmental law and trade
- Environmental economics
- Environmental energy management
- Media, environment education and sustainable development
- State of the environment report and related issues
- Population and environment

The ENVIS Focal Point publishes *Paryavaran Abstracts*, a quarterly journal carrying abstracts of the environmental research conducted in the Indian context. It also publishes *ENVIRONEWS*, a quarterly newsletter that reports important policies, programmes, new legislations/rules, important notifications and other decisions taken by the ministry from time to time.

The website of the ministry, www.envfor.nic.in, has been developed and is maintained by the ENVIS Focal Point. The ENVIS Secretariat also maintains the web site www.sdnp.delhi.nic.in, which provides information on climate change and on several related topics such as disaster management, energy, forests, pollution and poverty.

the involvement and effective participation of a range of institutions and organizations in the country engaged in different spheres of the environment. ENVIS has therefore expanded as a network of numerous participating institutions and organizations. A network comprising 85 ENVIS Nodes with 25 ENVIS Centres have been established that cover the diverse subject areas of environment, with a Focal Point in the MoEF. The ENVIS nodes now exist in 30 government departments, 34 institutions and 21 NGOs.

Participation in World Summit on Sustainable Development (WSSD)

India participated in the WSSD held in Johannesburg in 2002, the primary objective of which was to review the progress made towards the commitments made 10 years ago at the Earth Summit, with reference to *Agenda 21* and other Rio agreements, including the Framework Convention on Climate Change. During the run up to the WSSD, MoEF initiated a preparatory process, which involved several multi-stakeholder consultations at the national and regional levels, to identify and discuss issues relevant for India at the Summit. More than a 1,000 people participated in these consultations. Based on India's participation, a document titled *Sustainable Development: Learnings and Perspectives from India* evolved. To involve a wide cross-section of civil society in the discussions, a media campaign was undertaken to disseminate commissioned articles and background information on WSSD-related issues.

The MoEF also sought to create awareness about sustainable development and WSSD among children, by organizing essay writing, painting, poetry writing and photography competitions across the country. More than 100,000 students from 14,000 schools participated in these competitions.

Hosting of COP-8

As a party to the UNFCCC, India had the privilege of hosting the Eighth Conference of Parties (COP-8) in New Delhi from 23 October to 1 November 2002. More than 4,300 delegates from 170 countries attended the Conference, 52 officials and 395 NGO and other civil society delegates from India participated in various official and side events. On the final day, the parties adopted the *Delhi Declaration on Climate Change and Sustainable Development*, which reaffirms development and poverty eradication as the overriding priorities in developing countries, and implementation of the UNFCCC commitments according to the parties' common but differentiated responsibilities, development priorities and circumstances.

In order to create awareness among various stakeholders in the country about climate change issues, the ongoing international negotiations, and the emerging challenges and opportunities, the MoEF organized several events leading up to COP-8. In March 2002, it organized a high-level consultation of environment ministers and delegates from 35 countries who endorsed India's proposal for a Delhi Declaration. In addition, the MoEF facilitated 44 events by NGOs, half of which were organized by Indian NGOs, academic institutions, industry associations, and government ministries and departments. The events ranged from a cartoon exhibition on climate change to workshops and seminars on the Clean Development Mechanism, and climate change mitigation and adaptation strategies.

Initiatives under the aegis of India's Initial National Communication

As a part of its commitment to the UNFCCC, the Government of India, through the MoEF initiated the project titled 'Enabling Activities for the Preparation of India's Initial National Communication to the UNFCCC', or the NATCOM project in 2001. The MoEF was the executing and implementing agency for this project.

The process for the preparation of the National Communication adopted a broad participatory approach involving research institutions, technical institutions, universities, government departments and NGOs, necessitated by the vast regional diversity and sectoral complexities in India, duly utilizing and enhancing the diverse extant institutional capabilities. To facilitate the process, under the aegis of the project, 27 seminars and workshops have been conducted all over India for planning the work, developing linkages between climate change issues and developmental and economic processes, and for training and raising awareness on issues pertaining to different components of the National Communication (Figure 5.1).

The process has initiated efforts to identify areas of future research to strengthen the Initial National Communication experience, gaps and future needs have been identified for the development and strengthening of activities for creating public awareness, ensuring meaningful inputs into education, and enabling access to information. A website (www.natcomindia.org) has been developed for dissemination of information and publications arising out of the project.

The website of India's Initial National Communication.

Industry and Climate

As industry is one of the major contributors of GHG emissions, the MoEF organized conferences on 'Climate Change: Issues, Concerns and Opportunities' at different locations in collaboration with various chambers of commerce and industry. To create awareness about climate change issues related with the sector of economy most vulnerable to the consequences of the phenomenon, MoEF collaborated with the MoA, UNEP and the Consultative Group of International Agriculture Research, to organize a workshop on 'Adaptation to climate change for agricultural productivity: the South Asia expert workshop'. The MoEF also organized a workshop to brief the media and enlist their involvement in providing wide and informed coverage to the proceedings and activities of COP-8, as well as to the issues related to climate change.

Other Initiatives and Events

The MoEF promotes and supports other initiatives that in some way, direct or indirect, are significant in the context of climate change vulnerability, adaptation and emission abatement. Most of these have an education, training or outreach component. Some of these initiatives are listed below:

Afforestation

The principal aim, as stated in the National Forest Policy, 1988, is that it must 'ensure environmental

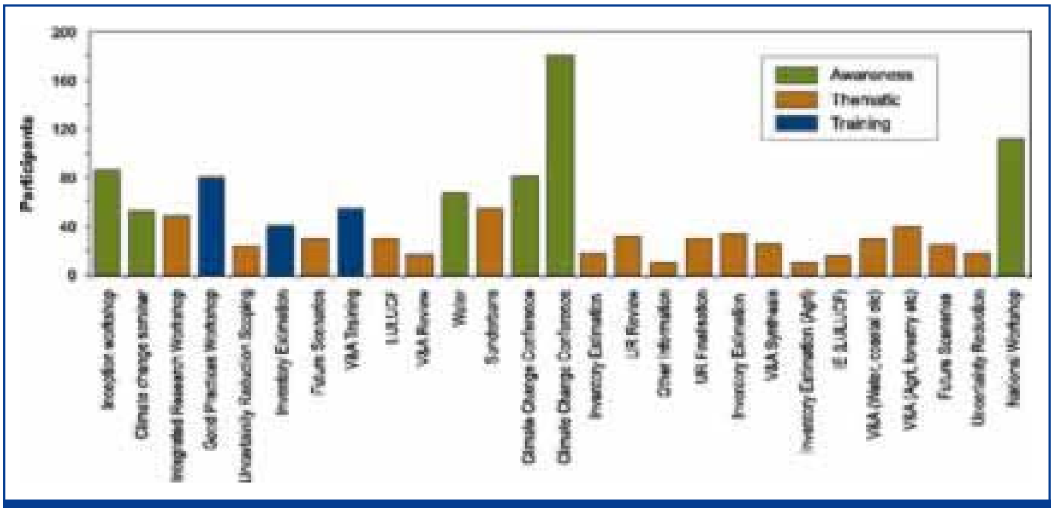


Figure 5.1: Workshops conducted under the aegis of India's Initial National Communication project.

Afforestation on common land through peoples' participation.

stability and maintenance of ecological balance including atmospheric equilibrium, which are vital for sustenance of all life-forms, human, animal and plant' (www.envfor.nic.in). The National Afforestation and Eco-Development Board is responsible for promoting afforestation, with special attention to degraded forest areas. One of its main function is to create awareness and help foster people's movement for promoting afforestation and eco-development with the assistance of voluntary agencies, NGOs, *Panchayati Raj* institutions, and others. The National Wastelands Development Board under the Ministry of Rural Development is similarly responsible for the restoration of degraded private lands.

Joint Forest Management

Recognizing that forests cannot be protected or regenerated without the active and willing involvement of the forest-fringe communities, the MoEF adopted the JFM strategy more than a decade ago. So far 27 states have issued orders to enable the participation of local communities with active support of state forest departments and NGOs (MoEF, 2002).

Coimbatore Charter

In January 2001, a national conference on environment and forests was held at Coimbatore, which resolved to protect and improve the environment and forests of the country in accordance with several measures decided upon. One of the resolutions of the Coimbatore Charter was that the central government would keep the state and UT governments informed about the developments on international issues related to the protection of the environment and forests. These would cover all subjects addressed under the various UN Conventions and agreements, including climate change.

GLOBE

The MoEF is the coordinating agency in India for GLOBE, a hands-on, internet-based science and education programme, which involves primary and secondary level students in more than 10,000 schools in nearly 100 countries. These students study, observe, explore and take environmental measurements related with atmosphere, water, soils, and land cover and biology. They report this data through the Internet to the GLOBE data archives, create maps and graphs to analyze the data, and collaborate with scientists and other students around the world on projects to better understand their local and the global environment, and the earth as a system (www.globe.gov).

Research

The MoEF has been funding research in multi-disciplinary aspects of environmental and ecosystems protection, conservation and management at various universities, research institutes and NGOs. The MoEF has also identified several areas for priority action, which include Clean Technologies and climate change. The MoEF and the UK Department for Environment, Food and Rural Affairs (DEFRA) are collaborating on a joint research programme on Impacts of Climate Change in India. The findings, data and knowledge generated by the various research projects provide valuable inputs for climate change awareness, education and training efforts (MoEF, 2002).

Education, training and outreach

The MoEF has a well-established institutional structure for education, training and public awareness. The Indian Council of Forestry Research and Education (ICFRE), Dehradun, is an autonomous organization of the ministry. It organizes and manages research, education and extension in the field of forestry, and runs doctoral and postdoctoral research programmes in various disciplines of forestry at different institutes under ICFRE. The Indira Gandhi National Forest Academy and the Directorate of

Forest Education, both at Dehradun, impart in-service professional training to the Indian Forest Service probationers, the State Forest Service and Forest Range Officers.

The Indian Institute of Forest Management, Bhopal, provides training in management and related subjects to officers from the Indian Forest Service, Forest Departments, Forest Development Corporations and forest-related industries, with a view to inculcating professionalism in forestry management. It also runs a two-year post-graduate diploma in Forestry Management, and a one-year M.Phil-level course in Resource Management. The Wildlife Institute of India, Dehradun, imparts training to government and NGOs, and conducts research and training on conservation and management of wildlife resources.

The National Museum of Natural History, in New Delhi, and the three regional museums at Mysore, Bhopal and Bhubaneswar, promote non-formal environmental education and creates environmental and conservation awareness through various outreach activities.

To strengthen public awareness, research and training in priority areas of environmental science and management, and environmental education, the MoEF has set up eight Centres of Excellence. Of these, the Centre for Environment Education, Ahmedabad; the CPR Environmental Education Centre, Chennai; and the Centre for Ecological Sciences, Bangalore, have been particularly active in organizing workshops, training programmes and seminars for teachers, communicators, NGOs and others on a variety of themes in environment and development, and pure and applied ecology respectively. All the eight Centres have the potential to increase climate change education, training and outreach efforts in their respective spheres of work.

The National Environment Awareness Campaign is a nation-wide programme supported by the MoEF to encourage NGOs and institutions to undertake programmes to create awareness about environmental issues. The ministry runs the Eco-clubs programme to mobilize youth for environmental action. The student members of Eco-clubs constitute the National Green Corps (NGC). The programme already reaches out to more than 50,000 schools across the country. The NGC has already initiated energy-related activities, to which climate change education could be added easily and seamlessly.

ROLE OF OTHER MINISTRIES AND DEPARTMENTS

While the MoEF is the nodal ministry in the Government of India for the subject of climate change, other ministries and departments have also been actively involved in creating awareness about energy conservation and climate change issues through sectoral initiatives, extension services, educational and training inputs and providing research support. As the energy sector is the major emitter of GHG, contributing about 61 per cent of the country's emissions in 1994, several outreach initiatives have been taken by various ministries in this area.

Ministry of Agriculture (MoA)

Agriculture, especially in the arid and semi-arid tropics, is the activity that is most vulnerable to climate change. A projected one-metre rise in the sea-level is expected to inundate about 1,700 km^2 of agricultural land in Orissa and West Bengal alone (IPCC, 1992). The most vulnerable section of society will be the poor, the marginal farmers and the landless agricultural labourers. The increasing frequency and intensity of extreme weather events will also have a direct bearing on agriculture. Recognizing the need for urgent action, the need to build capacity and to deal with climate change issues related to agriculture, a dedicated unit—Climate Change Cell—has been set up within MoA.

In the Ninth Plan Period (1997-2002) the MoA launched the National Agriculture Technology Project to strengthen research, education and human resources development in agriculture, through its national grid comprising 46 institutes including universities, research centres and regional stations. All of these form a large infrastructure for climate change research and outreach activities.

As agriculture in most developing countries is vulnerable to the impacts of climate change, the need for adaptive strategies becomes paramount. Thus, this became the focus of the MoA's activities at COP-8,

Educating farmers on manure management.

where it hosted workshops for experts, policy planners, negotiators and civil society on adapting agriculture to climate change.

Ministry of Home Affairs

The Ministry of Home Affairs (MoHA) is the nodal ministry for disaster management. Through the Disaster Risk Management Programme initiated in 2002, the United Nations Development Programme (UNDP) proposes to accelerate capacity building in disaster reduction and recovery activities at the national level and in some of the most vulnerable regions of the country, through community-based activities. The programme will support the MoHA to set up an institutional framework for disaster preparedness, prevention and mitigation. The focus of the programme is on awareness generation and education, training and capacity development of government officials in the areas of disaster risk management at the community, district and state levels. This will also enable them to help communities develop disaster plans.

Biogas plants and lanterns help rural households with their lighting and cooking needs.

Learning-by-doing workshop for children and villagers on various types of solar cookers.

An Energy Park at an institution in Gujarat.

As a joint initiative of the UNDP and the MoHA, a module on disaster management has been introduced in the revised curriculum of the Central Board of Secondary Education for classes 8, 9 and 10.

Ministry of Non-Conventional Energy Sources

The Ministry of Non-Conventional Energy Sources (MNES) manages one of the world's largest renewable energy programmes. The Indian Renewable Energy Development Agency Limited (IREDA), an agency of the MNES, conducts publicity campaigns to disseminate information about renewable energy technologies through the print and electronic media, seminars, exhibitions and business conferences. It has taken a number of initiatives for empowering women through renewable energy programmes. The MNES has set up the Information and Public Awareness (I&PA) Programme to create mass awareness about new and renewable sources of energy systems and devices throughout the country. These include initiatives such as, biogas plants (See Box 5.2), solar

Box 5.2: Managing Methane

The Satia Paper Mills, Muktsar, Punjab, used to generate large amounts of organic waste, including methane, as a result of its manufacturing process. They also used 20 tonnes of rice husk per day in their boilers, leading to the substantial emission of GHG. The conventional effluent treatment system was not able to meet the norms set by the Pollution Control Board, and the mill had become economically unviable.

In 1997, the mill switched to a technology, which provided a solution to both its effluent treatment and energy requirement problems. As part of the UNDP-supported "Development of high rate Biomethanation Processes as means of reducing Greenhouse gases emission" being implemented by the MNES, an Upflow Anaerobic Sludge Blanket Bioreactor was installed at the mill. The reactor uses the organic waste from the mill to produce biogas. The biogas is used in the boilers, resulting in the net saving of the operating cost of the mill. The use of rice husk is also avoided, which further reduces its emission levels. The new technology has meant 45 per cent reduction in chemical oxygen demand and around 80-85 per cent biological oxygen demand reduction.

This technology can be used in a variety of production processes where organic waste levels are high, including leather factories and tanneries, dairies, confectioneries, food processing units and breweries. Started in 1994, the MNES project serves not only to control emissions of methane but also utilizes it as a clean fuel. The project aims to provide technical assistance and institutional preparation for formulating a national strategy for biogas generation and utilization, in introducing, demonstrating and standardizing a wide variety of technologies, and in bringing about awareness amongst policy-makers, waste generators, and the general public.

cookers, improved wood stoves, solar lanterns, home lighting systems, street lighting systems, and solar water pumping.

To create awareness about the use and benefits of renewable energy products and devices, the MNES has also initiated an Energy Park Scheme. These parks are set up at public places and institutions that have a large inflow of people.

The MNES organizes business meets, workshops and seminars to promote renewable energy technologies; it also funds NGOs and other institutions to organize such events. The MNES has set up specialized technical institutions to constantly work on the upgradation of renewable energy technologies, and for manpower training. It also supports technology-specific training courses at academic institutions. The MNES has also instituted the National Renewable Energy (NRE) fellowships for Masters and Doctoral programmes in renewable energy.

Scientists and technologists working with the ministry, the state nodal agencies and other institutions engaged in R&D are sent abroad for training, study tours, conferences, and workshops to update their knowledge and skills.

Under the Government of India / UNDP Rural Energy Programme Support, the MNES has undertaken as a climate change mitigation effort, a demonstration project of community-managed gasifiers in the tribal areas of Jharkhand. A few UNDP/GEF assisted projects on reducing GHG emissions such as by developing small hydel resources in hilly regions have already been implemented, and others are also being proposed (MNES, 2002).

Ministry of Petroleum and Natural Gas

Every year since 1991, all the constituents of the Ministry of Petroleum and Natural Gas devote a full fortnight to improving the awareness on the importance and need for oil conservation.

In 1976, the Ministry established the Petroleum Conservation Research Association (PCRA). PCRA's outreach activities include the use of mass media, printed literature and outdoor publicity for increasing awareness about petroleum conservation among consumers. It also publishes a quarterly journal *Active Conservation Techniques*, and a newsletter. The

PCRA website (www.pcra.org) carries articles on energy conservation.

The PCRA organizes seminars, technical meets, workshops, clinics, exhibitions and *kisan melas* (farmers' fairs) for the dissemination of conservation messages and demonstration of conservation techniques and technologies. Its consumer meets bring together energy consumers, equipment manufacturers and energy consultants to solve the energy conservation problems and create awareness. The PCRA also supports energy efficiency and energy service companies (EECOs and ESCOs).

The Ministry of Petroleum and Natural Gas has also initiated the following innovative programmes:

- "*Boond Boond ki Baat*" (Story of Each Drop) is a radio programme launched in 2002-2003 presenting highly technical matter in simple language.
- "*Khel Khel Mein Badlo Duniya*" (Change the World through Simple Ways) is an educational TV programme for youth on the conservation of energy, water, environment, etc., and providing vocational guidance in vermiculture, integrated farming, etc.
- Involving school children in agriculture surveys and science exhibitions in select districts of the country.
- Organization of two-wheeler rallies for women during the annual oil and gas conservation fortnight with the twin aims of women empowerment and sensitivity towards oil and gas conservation.

Ministry of Power

The Ministry of Power (MoP) is the coordinating agency for matters relating to energy efficiency for all conventional energy sources. Various steps initiated by Ministry of Power in the field of energy conservation and building public awareness are enumerated below:

***Energy Conservation Act, 2001*:** The Energy Conservation Act, 2001, reflects India's commitment to climate change efforts through efficient energy utilization. The Act focuses on the enormous potential for reducing energy consumption, by adopting energy efficiency measures in various sectors of the economy. Under this Act, the Bureau of Energy Efficiency (BEE) has been created by merging the existing Energy Management Centre (EMC). The functions of the BEE include prescribing guidelines for energy conservation, creating consumer awareness and disseminating information on the efficient use of energy.

The Ministry of Power has instituted National Energy Conservation Awards to recognize the participating industrial units that have made special efforts to reduce energy consumption. In the last five years of above award scheme, which is coordinated by the Bureau of Energy Efficiency, the participating industrial units collectively have saved 2397 million units of electrical energy; 9067 kilo litre of furnace oil; 2.76 Mt of coal and 11,585 million cubic metre of gas per year, resulting in substantial reduction in greenhouse gas emissions.

CENPEEP: The National Thermal Power Corporation (NTPC) of MoP, which today is the largest power utility in the country, established the Centre for Power Efficiency and Environment Protection (CENPEEP), a resource centre for state-of-the-art technologies and practices for performance optimization of thermal power plants. The CENPEEP was awarded the CTI World Climate Technology Award for supporting the adoption of more efficient coal-fired power plants in India. The Centre regularly holds workshops and offers hands-on training for power sector officials from the NTPC and SEBs. Dissemination of practices for improvement of efficiency of existing coal based power stations would help abating CO_2 emissions.

***Mass Awareness*:** A multimedia mass awareness campaign was launched country wide by the MoP to enlist the active cooperation of all stakeholders for the steps that have to be taken to improve the quality of supply and service as well as for the policy changes that are emerging to make the sector sustainable. This included awareness about the necessity of energy savings through energy conservation, thereby offsetting the additional requirement of power (generated primarily through coal, the mainstay of the Indian power sector) and therefore reducing GHG emissions. Both the print and electronic media was actively involved during the mass awareness programme. Information on various programmes/ initiatives taken up by the Ministry of Power in various areas of power sector are regularly disseminated through print/electronic media, MoP's website, workshops and conferences.

Training: The NTPC and other central PSUs under the MoP regularly conduct environment awareness training programmes for their employees. Further, the concerned specialists working in various areas are regularly deputed for specialized training, study tours, conferences and workshops, to enable them to update their knowledge and skills for overall improvement in the respective areas.

The Power Management Institute of NTPC organizes training courses in the field of environment for its employees and other power utilities for general awareness and improving their skills.

The Ministry of Power and central PSUs regularly conduct national and international level workshops, and conferences on various aspects of power plants to share best practices and to adopt efficient new technologies/systems and to stimulate discussion on key issues. Two of the recently held conferences are listed below:

- conference on 'Coal and Electricity in India' jointly organized by the MoP, Ministry of Coal and International Energy Agency (IEA), on 22 and 23 September 2003 in New Delhi.
- international conference on 'Thermal Power Generation—Best Practices and Future Technologies' organized by the NTPC on 13-15 October 2003 in New Delhi.

Ministry of Road Transport and Highways

The Ministry of Road Transport and Highways is responsible for progressively introducing tighter auto emission norms and for the gradual alignment of auto specifications with the prevalent ECE standards, while taking into account the national requirements.

Ministry of Science and Technology

The key to a strong and efficient global action on climate change lies in building an effective science - policy interface. The DST of the Ministry of Science and Technology supports and fosters research in the area of atmospheric sciences, including meteorology and climate change. This research provides the knowledge that informs policy, and forms the basis for building sound strategies for sustainable development. It also forms the information base for outreach and education programmes.

The DST established the Technology Information, Forecasting and Assessment Council (TIFAC), an autonomous organization, to monitor global trends, to formulate preferred technology options for India, promote key technologies and undertake technology assessment and forecasting studies in selected areas of the national economy.

The TIFAC promotes and facilitates the commercialization of Clean Energy Technologies. Its outreach activities include various Technology Assessment and Technomarket Survey Study reports, that help both industry and financial institutions. These reports are available on line on the TIFAC website (www.tifac.org.in). It also brings out technology linked business opportunity publications on issues like techniques to improve the operational efficiency of thermal power stations. The TIFAC also conducts awareness and training workshops.

Every year since 1988, the Science and Engineering Research Council (SERC) of DST has been supporting summer/winter schools in emerging areas of Science and Technology at prestigious research and educational institutions in the country. Advanced Ph.D. students are considered to be the appropriate target group. A programme of two to four weeks duration is conducted by a faculty comprising of leading Indian scientists. Some of these programmes are in the area of atmospheric sciences, such as the one on Agro-meteorology (DST, 2000-2001).

The National Council for Science and Technology Communication (NCSTC) under DST, and Vigyan Prasar is an autonomous organization set up by the DST. The NCSTC undertakes various programmes and develops books, films and other resources for popularizing science and technology. Several of their efforts, although so far not strictly focused on climate change awareness, have immense potential for promoting the understanding about its various aspects (DST, 2001-2002).

Other Initiatives

Other ministries and departments of the Government of India, and those of the states and UTs also have specific programmes on awareness generation and education on the environment and sustainable development. For example, a drought proofing and sustainable livelihoods programme for decentralized planning was undertaken by UNDP-DFID and the Government of Orissa, implemented through Panchayati Raj institutions. It involved the community in deciding approaches to drought proofing and achieving livelihood sustainability. Such programmes aim at vulnerability reduction and environmental sustainability, strengthen adaptation capability and therefore, address climate change.

INDIAN INDUSTRY AND CLIMATE CHANGE

The Indian industry has played a crucial role in contributing to India's economic growth over the last few decades. However, as a major emitter of GHG and other pollutants, the industrial sector must be more socially and environmentally responsible (See Box 5.3). In recent years, pressures generated by legislation, consumer awareness and environmental activism including by the judiciary, have led to a growing realization in this sector, that it makes economic sense to adopt cleaner production and energy efficient practices and technologies. The industry associations have played a significant role in creating awareness among their members and facilitating their access to information, technologies, and other mechanisms to help Indian industry become environmentally responsible. All the major industry associations have climate change divisions and are instrumental in spreading awareness about the links between GHG emission abatement, energy efficiency and global cooperative mechanisms. However, the implementation and monitoring of these require further strengthening.

Box 5.3: Eco-fridge

A major initiative towards reducing the use of Ozone Depleting Substances (ODS) was taken by Godrej Industries Limited, a leading manufacturer of refrigerators in India. Godrej is now manufacturing Eco-fridges or environment-friendly fridges. The eco-fridge launched by Godrej Home Appliances under the brand name Pentacool is the result of the combined effort of Godrej and the NCL, Pune. The technology change is based on the use of safe pentane technology rather than choosing other harmful gases. The green refrigerator concept is being used to create awareness among the consumers about the adverse effect of harmful technology on the environment, and on the necessity of the adoption and use of environment-friendly technology.

Associated Chamber of Commerce and Industry of India (ASSOCHAM)

The ASSOCHAM is the oldest apex chamber of India and is actively involved in environmental and climate change-related awareness generation, and capacity building in the Indian industry. It has recently started Green Initiatives—providing information on issues such as cleaner production options, ISO 14000, green ratings for the industry, greening supply chain, advanced EMS auditing course, environment legislation, pollution prevention and waste minimization, hazardous waste management, and energy auditing.

Apart from these, there are many sector-specific industry associations, such as the Cement Manufacturers Association, the Indian Sugar Mills Association, the All India Brick and Tile Manufacturers of India, the Society of Indian Automobile Manufacturers, the Steel Furnace Association of India, the All India Induction Furnace Association, the All India Air Conditioning and Refrigeration Association, the All India Small Paper Mills Association, the Jute Manufacturers Development Council. These are involved at different levels in educating their members in climate-friendly development, energy efficiency improvement and cleaner technology initiatives.

There are also many bilateral and multilateral initiatives in collaboration with the Indian industry for information dissemination and awareness generation on clean technology, process improvement, the Clean Development Mechanism (CDM), industrial ecology, corporate accounting of GHG emissions, etc.

Confederation of Indian Industries

The Confederation of Indian Industries (CII) strives to strengthen the role of Indian industry in the economic development of the country while working towards its globalization and integration into the world economy. The CII has established the CII Climate Change Centre (also called 4C) whose main objectives are to spread awareness of climate change issues within the Indian industry; promote consensus on climate change flexibility mechanisms, particularly the CDM; and to build local capacity to develop climate change mitigation projects.

The Centre has developed a website (www.ciionline.org/busserv/climatechange.html) and has also set up searchable databases for information dissemination. It organizes workshops and training programmes, and publishes books, reports, policy papers, newsletters and case studies. The website provides information on issues such as mitigation opportunities in various sectors, and also helps facilitate partnerships with foreign collaborators.

In an effort to involve the industry in contributing to climate change negotiations, 4C has organized several events to create awareness among industry leaders about the implications of climate change for the Indian industry, and about the flexibility mechanisms being negotiated. The Centre also helps facilitate linkages between industries to promote the transfer of efficient technology with the help of foreign collaborators.

CII is a programme partner in the Greenhouse Gas Pollution Prevention Project-Climate Change Supplement, which aims to build local capacity and create a forum for greater dialogue and technical cooperation between the US and Indian governments and other stakeholders (www.climatechangeindia.com). Some issues of the *CII Newsletter* have focused on climate change. CII has also prepared a manual on *Climate Change Project Development* for the industry.

Federation of Indian Chambers of Commerce and Industry

The Federation of Indian Chambers of Commerce and Industry (FICCI) has, over the years, influenced the corporate sectors' sensitivity to environmental issues. The Federation has taken notable initiatives towards disseminating information to Indian industry about climate change mitigation.

FICCI has established an Environmental Information Centre (EIC). The Centre aims at providing

Some Indian Websites on Climate Change

Website	Organization
http://envfor.nic.in/cc/index.htm	Ministry of Environment & Forest (MoEF)
http://sdnp.delhi.nic.in/resources/climatechange	Ministry of Environment & Forest (MoEF)
www.natcomindia.org	NATCOM Project, MoEF
www.emcisee.com	Ministry of Power and FICCI
www.teriin.org/climate	The Energy and Resources Institute (TERI)
www.ceeindia.org/greenhousegases	Centre for Environment Education (CEE)
www.cseindia.org	Centre for Science and Environment (CSE)
www.cleantechinitiative.com	Federation of Indian Chambers of Commerce and Industry (FICCI)
www.ciionline.org/climatechange/index.html	Confederation of Indian Industries (CII)
www.climatechangecentre.org	Development Alternatives (DA)
www.cleantechindia.com	Federation of Indian Chambers of Commerce and Industry (FICCI)
www.assocham.org/services/env	The Associated Chamber of Commerce and Industry of India (ASSOCHAM)
www.developmentfirst.org/india	Indian Institute of Management, Ahmedabad
www.eeibs.com	Indian Institute of Management, Bangalore

comprehensive information about environment regulations, technology options, guidelines and manuals to enable Indian industry to become environmentally responsible and competitive. The EIC has four regional centres in Mumbai, Hyderabad, Delhi, and Kolkata.

EIC is also assisting the Indian industry in reducing GHG emissions through the Clean Technology Initiative (CTI). Under this initiative it has established a website www.cleantechindia.com, which is the virtual portal on 'clean technology' for the Indian industry. It serves as a clearing house of organized information for industry to address environmental issues, including those related to climate change, and as a platform for information sharing on environmental issues and solutions.

FICCI, in collaboration with the MoP's Energy Management Centre (EMC), has developed a web-based Information Service on Energy Efficiency (ISEE). The website www.emcisee.com is the portal for EMC. It is the only Indian information service on the Internet dedicated to disseminating technical and commercial information to energy sector-related producers, manufacturers and service providers, besides providing energy efficiency guidelines and best practices manuals to the industry.

THE ROLE OF CIVIL SOCIETY

Several civil society initiatives have sought to build capacity and create awareness about climate-friendly issues. Grassroot level activities are undertaken that seek to improve the ability of communities to manage their natural resources, generate sustainable livelihoods, develop infrastructure and participate in decision making, thereby improving their capability to cope with climatic stresses. Creating awareness and empowering rural womenfolk is an important initiative by many NGOs in India. These include facilitating creation and spread of grass root-level Self Help Groups.

Some leading professional organizations in India are involved in a wide range of climate change-related activities—research, awareness generation, advocacy, capacity building, developing technologies, developing and implementing projects. 'Adaptation'

Awareness generation in rural areas.

initiatives at the grassroots level have emerged in a variety of ways: some are initiated, catalyzed, organized and supported by NGOs; some by community-based organizations; and some are the efforts of individuals or groups who joined to tackle vexing local problems. Some of these initiatives tap resources through various development schemes of the government; some raise their own funds; while bilateral or multilateral funding agencies and programmes support others. The work of some leading NGOs is indicated below.

Centre for Environment Education

The Centre for Environmental Education (CEE), is a national institute engaged in developing innovative programmes and materials to increase awareness about the environment among children, youth, the general community, and decision-makers. It was set up in 1984 as a Centre of Excellence in Environmental Education, supported by the MoEF.

The CEE developed an information kit and a website (www.ceeindia.org/greenhousegases) on market opportunities in trading emission reductions in GHGs. Through its News and Features Service (*CEE-NFS*), it disseminates environment- related news items,

Capacity building for sustainable agriculture: A CEE initiative at Jasdan.

features and articles every month for non-exclusive use to several newspapers and magazines all over the country.

Its Internship Programme in Environmental Journalism, also offered through distance learning mode, has one module on climate change. The CEE also runs a Certificate Course in Environmental Education in partnership with the IUCN and WWF International. The CEE maintains an Environment Education Bank, a computerized database of environmental concepts, activities, case studies, and access information on books and other resources. As a coordinating agency for GLOBE, CEE helped initiate the programme by training teachers from schools all over the country, and developed activities to support the measurements related to weather and climate.

From 1995, the Rural Programmes Group of CEE has played a catalytic role to empower communities in 15 villages of Jasdan *taluka* in Gujarat, to upgrade and conserve their natural resources and undertake sustainable livelihood activities. These sustainable development activities contribute to enhancing the ability of the communities to adapt to climate change.

Centre for Science and Environment

The Centre for Science and Environment (CSE) is an independent, public interest organization that aims to increase public awareness on science, technology, environment and development. Established in 1980, today CSE is one of India's leading environmental NGOs specializing in sustainable natural resources management. Its strategy of knowledge-based activism is supported by campaigns, research and publications.

The CSE was one of the first organizations in India to become actively involved in creating awareness about climate change through research, publications and advocacy. It has sought to provide intellectual leadership by proposing strategies that will address ecology, economy, social justice and equity—the key principles of good governance**.** In 1991, CSE raised the issue of equity in managing climate change with its publication *Global Warming in an Unequal World*. The CSE's Global Environmental Governance (GEG) unit was created to educate civil society groups and government bodies about the issues, politics and science behind global environmental negotiations.

The CSE has also published the *State of Global Environmental Negotiations* (GEN) reports, which uncovered the issues and politics involved in these negotiations. It has launched a campaign to establish an equitable framework for a system of global environmental governance for climate change negotiations, and has been playing an important role at several international environmental negotiations. The GEG unit's popular newsletter *Equity Watch*, published on-site at such meetings, carries backgrounders, analysis, fact sheets and opinion about the climate change processes. The CSE also played an active role at the COP-8. It organized several side events, made presentations, brought out special editions of *Equity Watch*, issued press releases, made presentations and updated their website with news about the Conference.

CSE's fortnightly magazine *Down to Earth* regularly carries news and analyses of climate change issues, developments and events. From time to time, CSE also issues press releases and publishes briefing papers discussing various issues of the climate change debate. CSE's website www.cseindia.org has a section on climate change.

Consumer Unity and Trust Society

The Consumer Unity and Trust Society (CUTS) was established in 1983 as a consumer protection organization. Today, it works in several areas of public interest at the national, sub-continental and international levels. Under sustainable consumption, CUTS is focusing its work on Chapter 4 of *Agenda 21*. The endeavour is to understand and disseminate the concept of sustainable consumption and also its inter-linkages with other related areas, such poverty and climate change.

CUTS conducts campaigns, organizes events, and brings out newsletters. *Eco Consumer*, its quarterly newsletter, covers issues such as global warming, environment-friendly technologies and products. During COP-8, CUTS organized a workshop on the 'Impact of unsustainable production and consumption patterns on climate change: The role of consumer groups'.

Development Alternatives

Development Alternatives (DA) is a non-profit research, development and consultancy organization established in 1983. The organization's work includes design, development and dissemination of appropriate technologies, environmental resource management methods, and effective institutional systems. DA's outreach activities seek to create awareness among various stakeholders, such as NGOs, government agencies, industries, financial institutions, and communities on climate change issues. Its Climate Change Centre (CCC) has developed training modules on incorporating sustainable development concerns in climate change projects in India. Its Industrial Environmental Systems Group works with, and organizes, awareness and training workshops for the corporate sector, and small and medium enterprises on energy efficiency and resource conservation issues. The Urban Environment System Group has a nation-wide programme called CLEAN—India, to raise awareness among schoolchildren and resident's welfare associations about energy and resource conservation, and mobilizing communities for response measures.

The CCC organized the 'Inter-regional Conference on Adaptation to Climate Change' prior to COP-8, attracting over a 100 participants from 20 countries. The Conference deliberated on increasing community resilience for adaptation to climate change through sustainable development. It also organized an exhibition on environmental activities of school children, and another on sustainable handicrafts and other non-agricultural livelihood activities of self help groups.

The Energy and Resources Institute

TERI established in 1974, launched research activities on climate change in 1988, making it one of the first developing country institutions to work in this field. Its Centre for Global Environment Research (CGER) conducts research and outlines policy initiatives that integrate developing country concerns in addressing global environmental challenges. TERI constantly strives to spread awareness about climate change among the corporate sector (See Box 5.4), civil

Box 5.4: Green Corporate

In March 2000, *Business Today*, a leading business magazine, and The Energy and Resources Institute (TERI) conducted a cross-country study to look at environmental practices in corporate India. It was a study aimed at exploring how environmentally conscious corporate India was. The study, which looked at about 50 companies, revealed that more than three-quarters had an environmental policy. About 60 per cent had an environment department, and four out of every 10 had formal environment certification (ISO 14001).

The study also found that 20 per cent of the companies had an environmental policy operational at both the corporate office and the factory level, while in a majority of the others it was either at the plant level or at the corporate office level. An environmental audit system was also in place in about 70 per cent of the companies.

The chemicals and pharmaceuticals sectors scored high with respect to environmental consciousness in comparison to the other sectors. The minerals and mining sector also fared well, with green policies prevalent at both the corporate office and plant level.

Overall, the findings reveal that businesses have found that greening makes business sense. They are now increasingly investing in greener technologies, and almost half of the companies surveyed planned to include environmental improvements in their expansion plans.

society and decision-makers in India and other Asian countries, through workshops, business meets and seminars, print publications and web dissemination. TERI also trains corporate managers on the risks and opportunities for sustainable business due to climate change.

In the run-up to COP-8, TERI developed a climate change website (http://envfor.delhi.nic.in/cc) for the MoEF. During COP-8, it assisted the ministry by coordinating NGO events, and publishing a book titled *India: Climate Friendly Development* and a film called *Global Warning*. It also facilitated the development of a Children's Charter on climate change, which was presented to the COP-8 Plenary.

TERI's website (www.teriin.org) has a climate change section, which provides updated information with particular reference to India. TERI has recently set up a website (http://edugreen.teri.res.in), which helps schoolchildren and their teachers explore the environment through games and activities related to several topics including climate change. TERI publishes three research journals, three digest journals, eight newsletters, one bi-monthly e-magazine, one data book, and two online databases. TERI has published more than 20 print and online publications specifically on climate change. To date, TERI has produced 11 documentary films on topics ranging from rural resources to global warming, bound together by a common message that environmental problems can only be overcome by people's initiative and participation.

Winrock International India

Winrock International India (WII) is a non-profit organization working in the areas of natural resource management, clean energy and climate change. The Climate Change Programme at WII specifically addresses the challenge of climate change, working at the intersections of renewable energy and natural resources management. WII was the Facilitating Agency to the MoEF for preparing India's Initial National Communication (NATCOM) to the UNFCCC.

WII has a strong outreach programme whose repertoire of activities includes publications, education programmes, awareness and educational workshops including skill-oriented training for decision-makers, study tours, stakeholder partnerships and exchanges, press coverage and electronic communication. Its website (www.renewingindia.org) is one of the few portals in India focusing on renewable energy and the environment. WII also operates the (www.irenetindia.org) site that answers questions on promoting the use of renewable energy in the rural sector in India. In addition to publishing several newsletters, most of them to renewable energy.

Other community-based initiatives

Community development, knowledge sharing and grass root-level communication for rural people are important initiatives for a predominantly rural society like India. There are many NGOs in India that are working on strengthening the adaptive capacity of poor people to various stresses, including climate change, through education, training, public awareness and demonstration projects. It is not possible to list all of their efforts and achievements here, but they are making a positive change at the grass root-level. There are many successful experiments in India on increasing community resilience to stresses of various kinds, through shared local efforts. One such example is the rural electrification through a micro-hydel project at Thulappally in Kerala, undertaken by the Malanadu Development Society (See Box 5.5). Not only has the project provided electricity to 160 households in this remote village, it has also led to capacity building of local people in community power management and energy conservation, reduced their dependence on the neighbouring forest for fuel wood, reduced deforestation, prevented carbon emissions that electricity from a thermal power plant would have generated, and also improved the quality of life of the villagers.

One of the best-known examples of rural development and self-reliance in India is that of Ralegaon Siddhi. This barren and drought-stricken village in Maharashtra has been transformed through community efforts, facilitated by a simple man called Anna Hazare. He made sure that each villager had a stake in the prosperity of the village. Through participatory decision making and collective action, and the selective tapping of government schemes, the village today is prosperous and self-reliant, and can withstand even years of harsh drought.

Box 5.5: From Darkness to Light

Bounded by the River Pampa on one side, and the dense Sabarimala forests on the others, Thulapally in Kerala was till recently, fairly secluded from the rest of the world. Agriculture is the mainstay of the local economy and the land holdings are small and marginal. Animal husbandry is practised as a supplementary activity. There are mostly homestead-type farms, and houses are scattered across the village. Most of the domestic fuel needs are met by fuelwood.

The Malanadu Development Society (MDS) is a local NGO that has been working in this area for some time. Due to MDS facilitation, a 12-km stretch of road, and two major causeways across the rivers have been built. All of this has helped in the development of the village, but the community continued to feel the lack of electricity, as Thulapally was not connected to the main grid line, because it was too far away from it. It was in the late 1990s that the people of Thulapally requested the NGO to help them do something about bringing electric power to the village.

Power to the People

The Society's technical personnel surveyed the village and, on the basis of their study, felt that it would be possible to generate electricity through a micro-hydel project here. This suggestion was discussed at length with the local community. After several rounds of discussion they were convinced of its benefits and a local Committee was set up for the implementation of the project. Several sub-committees were formed to look after specific aspects like organizing people and collecting materials.

The financial resources came largely from the UNDP under the Small Grants Programme. The community too contributed. As the project beneficiaries were identified at the beginning of the project, it became easier for the MDS to seek their contributions for infrastructure, labour and other materials required for the construction activities in the project. Coconut poles were provided by the people to function as lamp-posts. The project gathered steam, and within 50 days, the people had power!

About 146 houses were given connections, as well as 10 shops and establishments, and five institutions. Each house was allowed four Compact Fluorescent Lamps. Additionally, 25 houses were given power for television sets. Electricity was to be supplied for about six hours everyday, and a monthly charge of Rs 50 (about US$1) per household with four lamps was levied. The generators have a total installed capacity of 20 KW.

Almost overnight, the quality of life in the village changed. Quite apart from the immediate benefits, several long-term benefits are anticipated: a positive impact on the health of women, because of their reduced exposure to indoor air pollution; the long-term impact on educational attainments of the children of the village, who can now pursue their studies more easily; and reduced dependence on firewood from the nearby forests.

The management of the project is entirely in the hands of the local community. The technical maintenance of the generator is done by trained local youth. If there are problems in the distribution system, they are set right by the local electrician. There is a General Body of all power consumers that makes the policies and is the final authority. The General Body elects a nine-member Executive Committee that looks after the management and administration of the project.

If replication is the test of success, this initiative is indeed successful. In the nearby Moolakayam village, 28 families now have electricity generated through a similar initiative. In far away Idukki district, a similar micro-hydel project has been built, benefitting 51 families.

Small and mini-hydro power projects which have the potential to provide energy in remote and hilly areas, where extension of the grid system is uneconomical, is one of the thrust areas of the Government of India. By 2001, 420 small hydro power projects (up to 25 MW station capacity), with a total capacity of over 1423 MW, had been established in the country.

Another outstanding example is of work catalyzed by the Tarun Bharat Sangh (TBS), a voluntary organization, in reviving a traditional system of water harvesting in the drought prone Alwar district of Rajasthan state in western India, where the groundwater table had receded below recoupable levels. In 1985-1986, a severe drought hit the region, adding to the already bleak situation of vanishing livelihoods and mass migration. Convinced that one way to improve the situation would be to revive traditional practices that had sustained semi-arid Alwar and its populace in the past, TBS mobilized community action to revive the *Johad* (an earthen *bund* or check dam to conserve rainwater). Today more than 4,000 *Johads* are totally managed by the community. The changes brought about have been dramatic. Wells have been recharged; food production and biomass productivity have increased; the per capita income has also risen in the region. The effort has even brought back to life two rivers, the Aravari and Ruparel, which are perennial once more.

The government promotes and facilitates the adoption of information and communication technologies in rural areas, including Internet services. These are expected to provide information and knowledge centres to the rural population for activities, such as agricultural consultation, market information and health services.

THE ROLE OF THE MASS MEDIA

The press and other mass media play a vital role in helping inform the public about climate change problems and their possible solutions.

Print Media

An analysis of news clippings on climate change in *India Green File* for the period 1995 to 2002, shows that whereas till 2001, the number of items on climate change fluctuated within a range and did not show any significant trend, in 2002 there was a major spurt. In the period leading up to COP-8 held in New Delhi in 2002, the MoEF and some NGOs organized special briefings for the media to facilitate informed reporting. The Press Information Bureau, a government-owned news agency, issued at least two-dozen press releases during and immediately before COP-8.

The CSE's fortnightly magazine *Down To Earth* has carried the highest number of articles related to climate change of any periodical in India. These articles dealt with the Kyoto Protocol and international climate change negotiations (19 per cent); GHG emission abatement activities and strategies (11 per cent); general reporting on climate change and related issues (37 per cent); and reports on scientific studies and research (33 per cent). Among the mainstream English-language newspapers scanned by *India Green File, The Hindu* carried the maximum number of climate change news and articles. Among the financial newspapers, *Business Standard* had the highest coverage.

Electronic Media

So far, the electronic media in India does not appear to have paid much attention to issues related to climate change. However, Development Alternatives produced 32 episodes of a weekly environment and business magazine called 'The Green Show' for three satellite channels. Several of the episodes were directly or indirectly related to climate change. A similar series of 30-minutes duration was commissioned and telecast on Doordarshan, India's national television service. TERI has produced 11 documentary films, some on energy and one on global warming, which were telecast on prime time national network as TERRAVIEW.

However, the access of Indian television viewers, is not limited only to Indian channels. International channels such as National Geographic, Discovery, as well as news channels such as BBC and CNN are also an important source of information about environmental issues and debates. Figures 5.2, 5.3 and 5.4 indicates the increasing trends of appearance of climate change issues in various media.

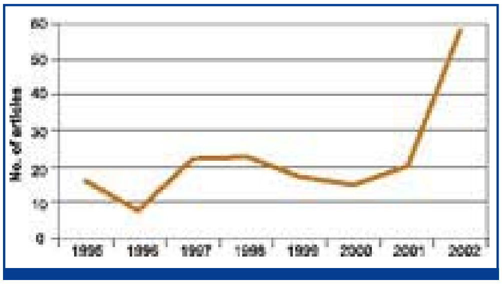


Figure 5.2: Trend of climate change reporting in India since early 1990s.

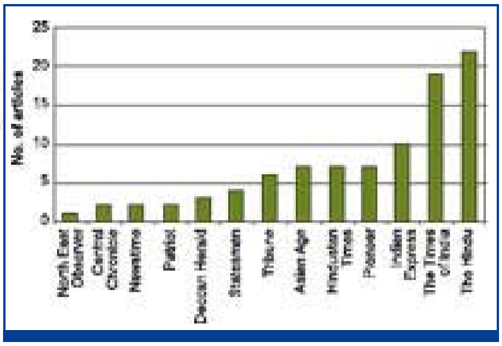


Figure 5.3: Number of articles on Climate change reported in news papers.

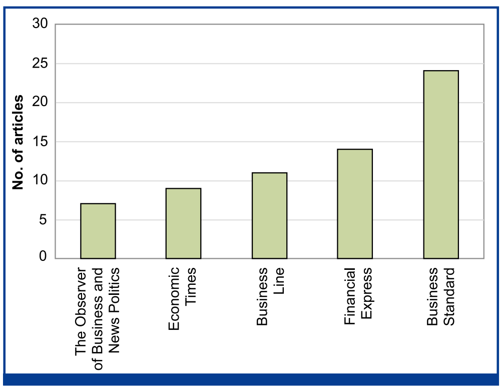


Figure 5.4: Climate change articles reported in financial dailies.

Climate Change Outreach for Children

Environmental education, both through the formal and non-formal routes, is an important medium for creating awareness about climate change among children and youth. India today has a formal policy framework and an institutional structure in place, through which environmental education is being promoted.

The National Education Policy, 1986, addressed the significance of environmental orientation to education at all levels. Guided by this policy, the National Council of Educational Research and Training (NCERT) and the Departments of Education in various states of India have been working to incorporate environmentally relevant components in the curricula and textbooks. Simultaneously, NGOs all over the country have developed innovative programmes and materials to address local environmental concerns. A few NGOs specializing in climate change and energy research have created programmes specifically on climate change. Some of these initiatives and ideas are gradually becoming part of the formal education system.

Students recording temperature data at a GLOBE school's weather station.

The Indian government has launched several environmental education initiatives, in addition to providing funding support to NGOs for such activities. Some examples of education and outreach efforts by the government and NGOs aimed specifically at climate change, energy efficiency, renewable energy and related issues, are described below.

Non-formal Education and Outreach

GLOBE

In 2000, India joined the GLOBE programme, which is coordinated in India by the MoEF. This hands-on, Internet-based science and education programme links students, teachers and scientists in nearly a 100 countries. Students collect data on various environmental parameters related to atmosphere, water, soil and vegetation, and report their data to the GLOBE website. These observations, in conjunction with related learning activities, enhance the students' understanding of the earth as a system and factors regulating its climate.

Awareness generation on vehicular emissions amongst children.

Petroleum Conservation

The Petroleum Conservation Research Association (PCRA) has been actively involved in promoting awareness about conserving petroleum products. Many of its activities and messages are also targetted at children. PCRA's website (www.pcra.org/children) has a section specifically designed to educate children about petroleum conservation.

Pollution Monitoring

The CSE was one of the first organizations to actively work towards creating awareness about climate change among all sections of society, including children. The CSE has established a Pollution Monitoring Laboratory to monitor and analyze the ambient air quality of schools in Delhi. The project, carried out by the city's school children and youth, generates awareness among them about the local environment and helps them to better understand issues related to GHG and climate change. The CPCB and the Delhi government also help to create awareness among the general public and students on vehicular pollution.

PROBE

The DST has launched a scheme called the Participation of youth in Real time/field Observation to Benefit Education (PROBE) linking students, teachers and the scientists in the collection of data on various meteorological observations. The programme was launched in 2002, in the state of Uttaranchal in a 100 schools. One objective of this programme is to create a database on meteorology, climate, natural resources and related fields, so as to improve the scientific understanding of weather and climate and their local impact in mountain regions.

NEAC and NGC

The National Environment Awareness Campaign (NEAC), launched by the MoEF in 1986, seeks to create environmental awareness among students, youth, teachers and rural populations. The National Green Corps (NGC) is another initiative by the MoEF to involve students in environmental action projects, thereby enhancing their understanding of and involvement in environmental issues.

Awareness on Renewable Energy

The MNES has been instrumental in creating public awareness on various renewable energy sources and energy efficiency devices. Most of their outreach programmes are targetted at the general public, including children. The MNES organizes drawing, poster, working model and essay competitions on renewable energy, and has made a special effort to include mentally and physically challenged children in these competitions. It has also set up Energy Parks at several locations in the country, in order to create awareness among people, particularly students, about the use and benefits of renewable energy systems and devices.

Science and Technology Popularization

The National Council for Science and Technology Communication (NCSTC) has been organizing and supporting numerous science exhibitions, fairs, street plays etc., on various themes for students across the country. One such event was a two-day awareness programme on the weather, environment and climate, organized by Karnataka Rajya Vijnana Parishad and the Indian Meteorological Society (IMS), Bangalore, in July 2001. Nearly 2,500 students and 500 teachers from 200 local schools attended the programme. The programme included displays by the ISRO and by the Disaster Management Cell of the IMD.

The NCSTC's science and technology popularization programme on the 'Application of Science and Technology in Industry' sensitizes students to various 'clean' industrial technologies and energy efficiency mechanisms, by facilitating visits to industrial units.

School Energy Project

As part of the School Energy Project, eco-club members in Ahmedabad started action projects aimed at reducing energy bills in their schools and homes. 'Energy Rooms' have been set up in participating schools, which house posters, models, and other resources for creating awareness among students on issues related to energy, such as the need to conserve fossil fuel, and control particulate and GHG emissions. The CEE organizes the Clean Green Programme every summer and students often undertake action projects on energy conservation.

Publications

The CSE brings out *Gobar Times*, a science and environment magazine for children. The post COP-8 issue of *Gobar Times* focused on climate change. TERI has published a book titled *Making Sense of Climate Change*, meant primarily to raise the awareness of secondary school students about climate change. Winrock International India (WII) brings out a newsletter named *REsource* on renewable energy education meant for secondary-level students and teachers. The newsletter disseminates information on the use and potential of clean renewable energy technology and encourages schools' involvement and interest in this sector.

Websites

Websites such as EduGreen (http://edugreen.teri.in) helps students and their teachers explore the environment through games and activities related to topics such as air pollution, energy, and climate change. Similarly, portals that deal exclusively with issues on energy and environment and renewable energy for school children are www.renewingindia.org/edu.html and www.winrockindia.org/child/index.htm, which also have a section on climate change. These websites have been developed by several NGOs.

Activities at COP-8

The CSE also assisted students to produce a special edition of *Gobar Times* during COP-8, in which children interviewed delegates and reported on the various events. During COP-8, school and college students organized a demonstration and a protest march demanding the reduction in CO_2 emissions and equal per capita entitlements to the atmosphere. Almost 120 students from 25 schools of Delhi prepared a Children's Charter on Climate Change, which they presented to the COP-8 Plenary. The MoEF and the United Nation's Environment Programme supported the event.

CLIMATE CHANGE IN HIGHER EDUCATION

A judicial directive by the Supreme Court of India in 1991, mandated environmental education at every level of formal education. A growing number of universities and technical institutions are offering foundation courses that will sensitize students to environmental issues, including climate change. However, the need is being increasingly felt for special courses in different professional disciplines. For example, businesses are feeling the pressures of environmental legislation and the need for environmentally responsible management practices. Recognizing this trend several business schools in India, as also elsewhere, have already introduced environmental management courses in their MBA curriculum, with the IIM, Ahmedabad (IIMA) and IIM, Bangalore taking the lead.

Agriculture Education

The Indian Agricultural Research Institute (IARI) is India's premier national institute for agricultural research, education and extension. The Division of Plant Physiology at IARI offers a course on Global Climate Change in the second trimester of its Masters programme, and has been conducting research on the impacts of climate change on crop productivity.

Education for Civil Servants

The Lal Bahadur Shastri National Academy of Administration at Mussoorie, is the Government of India's premier training institution for higher civil services in the country. The Academy is introducing a clean energy curriculum that will focus on sustainable energy management and its linkages with GHG emissions, public administration, economics and management.

Initiatives at Universities

Climate change is an active focus of activities at the Jadavpur University (JU) in Kolkata. The Department of Economics offers a masters-level course on

Resource and Environmental Economics, with a climate change component. The M.Phil. programme in Environmental Studies also deals with climate change. At the Ph.D. level, at least five research projects are in progress on climate change issues across various disciplines. The University has set up a Global Change Programme that proposes to start a teaching programme at the M.Phil. level on global change issues. It also conducts refresher courses for university and college teachers in economics, environmental economics, environmental science, power engineering, and international relations. All these courses have introduced a component on climate change issues over the past three to four years.

Management Education

In pursuance of the objective of greening higher education, the MoEF has taken the initiative to introduce and enhance the environment content in business and management education. Under this initiative, three consultative workshops have been conducted so far and a website (http://www.eeibs.com/) has been launched to infuse environmental concepts into management education.

A review of the syllabi of environmental courses already being offered at some leading management schools in India such as the IIM at Bangalore and Kolkata shows that climate change is already part of some of the courses. Climate change research has been a major focus of the energy and environment policy studies at the Public Systems Group of the IIM, Ahmedabad. At least half a dozen students at IIMA are currently working on climate change-related topics for their doctoral research, and several have worked on such topics in the past decade.

Research

Many eminent researchers in India have contributed and are contributing to climate change research. Their contribution to various reports of IPCC is significant. Similarly, many premier institutes, including IIMs, IITs and IISc, are involved in climate change research. Most of these research teams have participated in the preparation of this document. The research focus at the Centre for Ecological Studies, IISc, Bangalore has been on the impact of climate change on forests and natural ecosystems in India, on tracking carbon flow in Indian forests, the potential of forestry as a climate mitigation option, and the economic and institutional aspects of forestry mitigation options and adaptation to climate change.

The IIM, Ahmedabad is the premier institute in India, with collaborations with the best research teams in the world, on economy-energy-environment modelling research. The Indira Gandhi Institute of Development Research (IGIDR) is an advanced research institute established in Mumbai by the RBI, for carrying out research on development issues from a multi-disciplinary point of view. It offers PhD and M. Phil. programmes on environmental studies, including climate change issues. The IGIDR also offers special lectures and short courses on climate change.

The Centre for Global Change Research, a unit of the Radio and Atmospheric Sciences Division at the National Physical Laboratory, New Delhi, conducts research in several aspects of climate change, and also offers a doctoral programme.

TERI School of Advanced Studies, set up in 1999, is evolving as a research university. The three Centres of the School namely, the Centre for Energy and Environment, the Centre for Bioresources and Biotechnology, and the Centre for Regulatory and Policy Research, offer doctoral programmes in their respective fields, which also include research on issues such as forestry and climate change, and policy development in energy, climate change, and transportation.

Technical Education

Due to the interface of climate change with energy, at several institutions, climate change becomes a part of courses or programmes on Clean Energy Technologies and Renewable Energy as at the IIT, Delhi (IITD). The Department of Atmospheric Sciences at IITD is involved in scientific and technological aspects of climate change research such as climate modelling. The School of Management at IIT, Bombay focusses on research on the impacts of climate change. There are many more universities and institutes that have ongoing research on various aspects of climate change. Many of these have participated in preparing India's Initial National Communication to the UNFCCC.

CONCLUSION

Based on the review of the existing programmes, some areas that need strengthening are: the link between research output and outreach input; a focused inclusion of climate change in academic curricula at various levels; a more active involvement of mass media in covering climate change issues; and the integration of climate change concerns into consumer education. The initiatives to create awareness among the industry also need to be stepped up to reach every industrial estate and unit in the country.

The need is obviously to go beyond current efforts by strengthening, expanding and sustaining outreach and capacity-building efforts. It is necessary not only to create a requisite level of awareness and set up information systems, but also to establish and institutionalize adequate mechanisms to ensure access to information, and also to build the capacity required for taking necessary action. Therefore, the task requires a multi-pronged and multi-layered approach, linking together of several players and stakeholders, and adequate sustained financial resources.

Effective action by the industrial sector, for example, would require creating awareness among not only local industrial associations and individual units, but also among the financial institutions who would fund initiatives to support clean technologies and GHG emission abatement options; consultants to industry to enable them to build emission concerns and emission trading options into their plans and strategies for their clients; lawyers specializing in industrial law so that they can advise their clients about compliance issues and penalties or disincentives, as well as incentives; business journalists who can contribute by their reports and analyses of government policies and mitigation options; enforcement officials of the central and state Pollution Control Boards; and policy-makers who make industrial policies; and even legislators.

To create awareness in these groups would require structures and mechanisms. Integration of climate change issues and laws within the curriculum, and seminars and training programmes organized by the Bar Associations or other professional bodies, could be the pre-service and in-service routes for creating awareness and understanding among lawyers; media briefings, internships with environmental organizations, scholarships or sponsorships for focused research, and policies of the business media could be the routes for increasing the involvement of business journalists.

Outreach efforts of consumer societies, manufacturers of climate-friendly products, advertising agencies, the activation of the Ecomark scheme, and the Green Rating of products and their wide publicity, would contribute towards educating consumers to reject products that are not climate friendly in their manufacture, use or disposal. In addition, print and electronic media have an important role to play in influencing individuals and society.

The capacity of the present networks and institutional structures requires strengthening and enhancement. Several government agencies, professional bodies, NGOs and other civil society organizations are already involved in outreach and capacity-building efforts, and thus have the experience to continue and expand such efforts. There are possibilities to develop a synergistic framework of partnerships, drawing upon the expertize, experience and sectoral reach of its own institutional structure and others, some of whom may not be key players at present.

Chapter 6

Programmes Related to Sustainable Development

Programmes Related to Sustainable Development

Chapter 6

SUSTAINABLE DEVELOPMENT AND NATIONAL PLANNING

The single most important feature of our post-colonial experience is that the people of India have conclusively demonstrated their ability to forge a united nation despite its diversity, and to pursue development within the framework of a functioning, vibrant and pluralistic democracy. In this process, the democratic institutions have put down firm roots, which continue to gain strength and spread.

A planned approach to development has been the central process of the Indian democracy, as reflected in the national five-year plans, departmental annual plans, and perspective plans of various ministries of the central and state governments. For the last five and a half decades, the guiding objectives of the Indian planning process have been sustained economic growth, poverty alleviation, food, health, education and shelter for all, containing population growth, employment generation, self-reliance, people's participation in planning and programme implementation, and infrastructure development.

India is presently engaged with the Tenth Five-Year Plan, having achieved considerable progress during the previous nine five-year plans and three annual plans. The planning process in India aims to increase wealth and human welfare, while simultaneously conserving the environment. The national planning process lays emphasis on the promotion of people's participatory institutions and social mobilization, particularly through the empowerment of women, to ensure the environmental sustainability of the development process.

The growth of the Indian economy in the last two decades has led to a renewed emphasis on achieving significant reduction in poverty and providing basic minimum services like drinking water, health and education for all its citizens. Although India is still in the low-income category, with a per capita GDP of US$ 462 in comparison to US$ 911 for China, US$ 1,270 for the developing countries, US$ 22,149 for OECD countries, US$ 35,277 for the US, and US$ 5,133 for the world in the year 2001 (UNDP, 2002), India's skilled labour force, strong technical capabilities and increasing openness to economic reforms, have raised the potential for sustained faster economic growth.

India's poverty alleviation programmes over the years have focused on a variety of approaches. In the initial years of developmental planning, poverty was considered as essentially a rural problem and the strategies adopted focused on agricultural development and providing employment to the poor in rural areas. Specific programmes such as the Small Farmer's Development Agency (SFDA), the Programme for Marginal Farmers and Agricultural Labourers (MFAL), the Drought-Prone Area Programme (DPAP), the Integrated Rural Development Programme (IRDP), and the Development of Women and Children in Rural Areas (DWCRA), were launched. Based on past experiences with urban poverty alleviation programmes, an integrated programme called 'Swarna Jayanti Shahari Rozgar Yojana' (SJSRY) was launched in 1997, streamlining all the earlier efforts of employment generation and slum development in urban areas. Similarly, the different employment programmes for the rural areas have been brought under the umbrella of 'Sampoorna Gramin Rozgar Yojana' (SGRY) in 2001.

The rural population requires banking services that are accessible and flexible in terms of the bank timings, in order to minimize transaction costs. In this context, micro-finance programmes have emerged as

Women empowerment through Self Help Groups.

effective instruments of poverty alleviation in India. The Self Employed Women's Association (SEWA) and other micro-finance institutions have devised innovative credit programmes to address market failures and to deliver credit to the poor. These programmes use peer monitoring and a joint-liability structure to overcome the screening, monitoring and enforcement problems commonly encountered by formal lending institutions. They facilitate small loans to poor borrowers, often women organized into small groups, providing more accessible deposit facilities and with much greater attention to risk management.

Micro-finance could also be an advantageous way of introducing new information and communication technologies (ICT) in developing countries, contributing to reducing transaction costs and the digital gap. The Indian experience of ICT in the micro-finance sector is a unique and constant interplay between the diversity in the Indian micro-finance institutions. The benefits of the Internet to enhance micro-finance facilities, extending agricultural consultations and market information to farmers, and expert medical advice facilities to the vast rural population, are unquestionable to a country with over 600,000 villages. Self Help Groups (SHGs) provide an excellent facilitation mechanism for micro- finance in the Indian context. The process of organizing women into SHGs began in the late 1990s. The Small Industries Development Bank of India (SIDBI), the National Bank of Agriculture and Rural Development (NABARD), the Rashtriya Mahila Kosh (RMK) and many *Zilla Parishad*s have emerged as important players in the promotion of micro-finance through SHGs in India.

Information and communication technology can contribute tremendously to rural development.

Agriculture is a critical component of Indian sustainable developmental policies, since more than 650 million people depend on agriculture. The Green Revolution during the 1970s made India self-sufficient in food production through increased agricultural output based on high-yielding seeds, irrigation and fertilizers. At present, Indian agriculture is more intensive with regard to the use of inputs per hectare of land. The National Agricultural Policy (2000) seeks to achieve an output growth in excess of four per cent per year in a manner that is technologically, environmentally and economically sustainable. The five thrust areas for agriculture are to:

- Raise the cropping intensity of the existing agricultural land.
- Develop other rural infrastructure that supports not only agriculture, but also all rural economic activities.
- Develop and disseminate agricultural technologies.
- Diversify agricultural products, both geographically and over time.
- Reverse the declining trend of public investment in agriculture.

The Indian government has recently introduced a broad-based 'National Agriculture Insurance Scheme' (NAIS), which is an improvement on the existing Comprehensive Crop Insurance Scheme (CCIS). The


Modernizing agriculture is an important developmental priority.

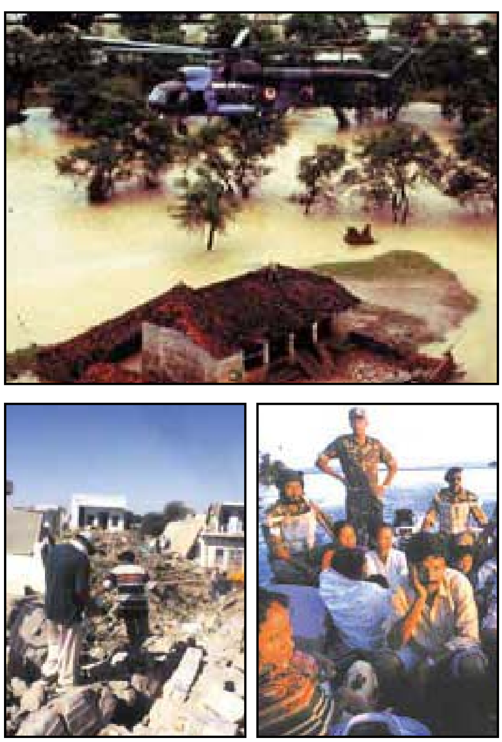
NAIS is available all over the country, covering diverse crops (food, horticultural, oilseeds and commercial), all farmers (small and marginal, loanee and non-loanee), and all yield losses due to natural, non-preventable risks. The premium rates vary from 1.5 to 3.5 per cent on the sum insured on food grain crops and oilseed crops and on an actuarial basis for annual commercial/horticultural crops. To meet claims beyond the liability of the insurance agency, a corpus fund is created with contributions from the Government of India and the participating states on a 1:1 basis. During the Tenth Plan (2002–2007), it is proposed to set up a National Crop Insurance Corporation to take over all the crop insurance functions.

The National Conservation Strategy and Policy Statement on Environment and Development, 1992, provides the basis for the integration of environmental considerations in the policies of various sectors. It aims at the achievement of sustainable lifestyles and the proper management and conservation of resources. The Policy Statement for Abatement of Pollution, 1992, stresses the prevention of pollution at the source, based on the 'polluter pays' principle. It encourages the use of the most appropriate technical solutions, particularly for the protection of heavily polluted areas and river stretches. The Forest Policy, 1988, highlights environmental protection through preservation and restoration of the ecological balance. The policy seeks to substantially increase the forest cover in the country through afforestation programmes. This environmental framework aims to take cognizance of the longer-term environmental perspective related to industrialization, power generation, transportation, mining, agriculture, irrigation and other such economic activities, as well as to address parallel concerns related to public health and safety.

The statutory framework for the environment includes the Indian Forest Act, 1927, the Water (Prevention and Control of Pollution) Act, 1974, the Air (Prevention and Control of Pollution) Act, 1981, The Forest (Conservation) Act, 1980, and the Environment (Protection) Act, 1986. Other enactments include the Public Liability Insurance Act, 1991, the National Environment Tribunal Act, 1995, and the National Environment Appellate Authority Act, 1997. The courts have also elaborated on the concepts relating to sustainable development, and the 'polluter pays' and 'precautionary' principles. In India, matters of public interest, particularly pertaining to the environment, are articulated effectively through a vigilant media, an active NGO community, and very importantly, through the judicial process which has recognized the citizen's right to a clean environment as a component of the right to life and liberty.

Forest conservation and enhancement are the stated objectives of national policy. Various policy initiatives have resulted in the increase of forest cover and a reduction in the per capita deforestation rate. The National Forests Policy envisages peoples' participation in the development of degraded forests to meet their fuel, fodder and timber needs, as well as to develop the forests for improving the environment through joint forest management (JFM). India has implemented a large number of progressive policies, programmes and measures to conserve and develop the forests, wildlife, mangroves and coral reefs, such as: the Forest Conservation Act (1980), the National Forest Policy (1988), the Wildlife Act, JFM, Social Forestry, banning of timber extraction in reserve forests, the improved cook-stove programme, and biogas to conserve fuelwood. Similarly, there are conservation programmes for mangroves, coral reefs and lake ecosystems. The National Wasteland Development Board is responsible for re-generating degraded non-forest and private lands. The National Afforestation and Eco-Development Board is responsible for regenerating degraded forest lands, the land adjoining forest areas, as well as ecologically fragile areas. The Forest Survey of India monitors changes in the forest area. All these measures have led to some stabilization of the forest area, a reduction in deforestation, afforestation, significantly contributing to conservation of the forest carbon sink. All these preparations will act as a buffer for the forest-dependent communities against the challenges posed by climate change.

India is fortunate to be endowed with both exhaustible (particularly coal) and renewable energy resources. Despite the resource potential and the significant rate of growth in energy supply over the last few decades, India faces serious energy shortages. This has led to an increasing reliance on imports to meet the growing oil and coal demand. The Tenth Plan strategy for the energy sector includes increasing the production of coal and electricity, accelerated exploration for hydrocarbons, equity oil abroad, introduction of reforms through restructuring/deregulation of the energy sector to increase efficiency, demand management through the introduction of energy efficient technologies/processes and appliances. The process of producing, transporting and consuming energy has a significant impact on the environment. The pollution abatement processes will form an important part of the development of the energy sector.



India has Disaster Management Plans for natural calamities.

India often faces natural calamities like floods, cyclones and droughts, which occur fairly frequently in different parts of the country. Sometimes, the same area is subjected to both floods and droughts in successive seasons or years. About 85 per cent of the country's total area is vulnerable to one or more disasters, and about 57 per cent of the area lies in high seismic zones, including the national capital. While not all natural calamities can be predicted and prevented, a state of preparedness and the ability to respond quickly to a natural calamity can considerably mitigate loss of life and property and restore normalcy at the earliest. Therefore, the Government of India has formulated detailed plans of action to deal with contingencies that arise in the wake of natural calamities, which are periodically updated. Detailed plans are formulated up to the district level.

The last decade of the 20 century has seen a visible shift in the focus of development planning—from the mere expansion of production of goods and services, and the consequent growth of per capita income—to planning for the enhancement of human well-being, more specifically to ensure that the basic material requirements of all sections of the population are met and that they have access to basic social services, such as health and education. A specific focus on these dimensions of social development is necessary because experience shows that economic prosperity, measured in terms of per capita income alone, does not always ensure enrichment in the quality of life, as reflected, for instance, in the social indicators on health, longevity, literacy and environmental sustainability. The latter must be valued as outcomes that are socially desirable in themselves and, hence, made direct objectives of any development process. (Box 6.1 and 6.2) They are also valuable inputs to sustain the development process in the long run.

In order to ensure the balanced development of all states, the Tenth Plan includes a state-wise break-up of the broad developmental targets, including targets

Box 6.1: Indian Developmental Targets

- Reducing the poverty ratio by five percentage points by 2007 and by 15 percentage points by 2012.
- Providing gainful and high-quality employment to the labour force over the tenth plan period (2002-2007).
- All children in school by 2003; all children to complete five years of schooling by 2007.
- Reducing gender gaps in literacy and wage rates by at least 50 per cent by 2007.
- Reducing the decadal rate of population growth between 2001-2011 to 16.2 per cent.
- Increasing the literacy rates to 75 per cent within the Plan period.
- Reducing the Infant Mortality Rate (IMR) to 45 per 1000 live births by 2007 and to 28 by 2012.
- Reducing the Maternal Mortality Ratio (MMR) to two per 1000 live births by 2007 and to one by 2012.
- Increasing the forest and tree cover to 25 per cent by 2007 and 33 per cent 2012.
- All villages to have sustained access to potable drinking water by 2007.
- Cleaning of all major polluted rivers by 2007 and other notified stretches by 2012.

Source: Tenth Plan Document, Planning Commission, 2002.

for growth rates and social development, which are consistent with the above national targets. These state-specific targets take into account the potential needs and constraints present in each state and the scope for improvement in their performance, given these constraints.

At the dawn of the new millennium, the Tenth Plan provides an opportunity to build upon the gains of the past and also to address the weaknesses that have emerged. The role of the government has to be redefined to that of a facilitator and developer of specific infrastructure such as rural infrastructure and road development. In other infrastructure sectors, for example, telecommunications, power, ports, etc., the private sector can play a much greater role, supported by an appropriate policy framework.

The process of development encompasses broader societal issues than merely economic growth. The conventional paradigm of economic development, which was woven around the optimal resource allocation, is now extended to include participative processes, local initiatives and global interfaces. The new vision views welfare as the *raison d'etre* of development. Under the emergent development perspective, while efficient resource allocation is best addressed by market mechanisms, the institutions are also a key component in a nation's capacity to use resources optimally. Thus, the institutions and policies have an important role in welfare maximizing development. The strong link between government

Box 6.2: Strategy for equity and social justice

- Agricultural development must be viewed as a core element of the national planning process, since growth in this sector is likely to lead to widespread benefits, especially to the rural poor. The first generation of reforms concentrated on the industrial economy and reforms in the agricultural sector were neglected; this must change in the Tenth Plan.
- The growth strategy of the Tenth Plan must ensure rapid development of sectors most likely to create large employment opportunities and deal with the policy constraints that discourage growth of employment. These include sectors such as agriculture in its extended sense, construction, tourism, transport, small-scale industry, retailing, information technology and communication-enabled services, as well as a range of other new services.
- There will be a continuing need to augment the growth momentum with special programmes aimed at target groups that may not derive sufficient benefit from the normal growth process. Such programmes have long been part of our development strategy and they must continue in the Tenth Plan as well.

Source: Tenth Plan Document, Planning Commission, 2002.

policies, organizational capacity, and social development is duly recognized. The provision of resources for social services and the creation of new partnerships for the delivery of services are important, and must be implemented within a framework that provides mechanisms for efficiency and accountability. The establishment of appropriate institutional frameworks to implement various development programmes has been an important component of development policies throughout India's planning effort since independence. These provide platforms to implement adaptation strategies for dispersed and informal sectors like watershed management, agriculture, rural health and forestry.

The three-tier *Panchayati Raj* institutions for local governance are the most fundamental system, transferring decision-making power to the grassroots level. The agricultural *cooperatives* have emerged as powerful institutions for rural development. Their organizational structures provide for the active participation of individuals at the local level. At present, there are large numbers of product or commodity-oriented co-operatives, such as in sugar, weaving, dairy, banking, and fisheries. In the mid-1990s, there were a total of 0.47 million co-operatives operating in different sectors, with more than 220 million members. However, the success of *Panchayati Raj* and co-operatives in a setting where literacy is low and the society is often fragmented into social and gender-based inequalities, requires substantial government interventions.

The development of institutions to elicit the community's participation in natural resource management has been a challenge for programme implementation. The social forestry programme was implemented through different plantation models, like farm forestry, community forestry, strip plantations, and rehabilitation of degraded forests and development of recreation forests. However, there were limitations to this approach. The National Forest Policy (1988) outlined the scope for people's participation in forest management. JFM, which followed, is a concept of developing partnerships between the forest-dependent communities and the forest departments on the basis of mutual trust and jointly defined roles and responsibilities with regard to forest protection and development. About 62,890 JFM committees covering an area of 14.25 Mha of forest land (about 21 per cent of the total recorded forest area in India), have since been established.

Community participation in natural resources management was extended to water resources as well, since it has emerged as a major challenge to public policy in recent years. Both irrigation systems and drinking-water supply systems were beset with several management problems. The irrigation sector has been facing the twin issues of sub-optimal sector planning and financial management on the one hand, and inadequate water management and maintenance on the other. Drawing lessons from the failure of supply-driven approaches in irrigation and drinking water projects, the recent initiatives have involved the users in the management of water resources. The *Water Users Associations* (WUAs) are central to the implementation of participatory irrigation management. The functions of WUAs include acting as an interface between the farmers and the main system management of the irrigation project as well as other concerned government agencies, water distribution, operation and maintenance of the irrigation and drainage system, collection of water charges and other user charges, land conflict resolution. There is a great deal of variability in the approaches to devolution and participation.

A beginning has also been made to involve users in both rural and urban drinking-water supply projects. It is based on the expectation that the implementation of a participatory demand-driven approach will ensure that the public obtains the level of service they desire and can afford to pay for. The recovery of operation, maintenance and replacement costs is expected to ensure the financial viability and sustainability of the schemes. The necessary reforms have been introduced in 1999 to the Accelerated Rural Water Supply Programme (ARWSP) implemented through the Rajiv Gandhi National Drinking Water Mission. In November 2002, the Government of India issued a notification on the implementation of participatory and community-led Swjaldhara Rural Drinking Water Projects.

Constitutional provisions and legal requirements have been used to achieve various standards and norms needed for development programmes. A variety of environmental regulations have been enacted to achieve goals of environment protection and preservation. Some of the major legislations for environmental protection include the Water (Prevention and Control of Pollution) Act (1974), the Forest Conservation Act (1980), the Air (Prevention and Control of Pollution) Act (1981), and the comprehensive Environment Protection Act (1986), the Energy Conservation Act (2001), and the Electricity Act (2003). Constitutional amendments were also made to incorporate environmental concerns into development programmes. The forty-second Amendment of the Constitution (1977) enjoined both the state and the citizens to protect and improve the environment and safeguard forests and wildlife. The seventy-third Amendment (1992) made the *Panchayats* responsible for soil conservation, watershed development, social and farm forestry, drinking water, fuel and fodder, non-conventional energy sources and maintenance of community assets. Various national policies, such as the National Forest Policy (1988) and the National Water Policy (1987 and 2002), are all important moves towards ensuring the sustainability of natural resources.

India is also a signatory to many of the international multilateral treaties in matters relating to environment, health, investment, trade and finance. The government has also incorporated the spirit of Agenda 21 in the form of two policy statements: the Abatement of Pollution and the National Conservation Strategy. The Abatement of Pollution conforms to the 'polluter pays' principle, involving the public in decision making, and giving industries and consumers clear signals through market mechanisms about the cost of using environmental and natural resources. The National Conservation Strategy and Policy Statement on Environment and Development have made environmental impact assessment mandatory for all development projects, right from the planning stage.

NATIONAL PLANNING AND CLIMATE CHANGE

The Tenth Five-Year Plan also reflects the Government of India's commitment to the United Nations Millennium Development Goals (2002). The UN goals include halving extreme poverty, halving the proportion of people without sustainable access to safe drinking water, halting the spread of HIV/AIDS and enrolling all boys and girls everywhere in primary schools by 2015. Many of the Indian national targets are more ambitious than the UN millennium development goals, like: doubling the national per capita income by 2012, all villages to have sustained access to potable drinking water by 2007, halting HIV/AIDS spread by 2007, and all children in schools by 2003 (Table 6.1). They reflect the commitment of the Government of India to the UNFCCC, the Rio Declaration (1992) on Agenda 21 at the UN Conference on Environment and Development, the Millennium Declaration at the UN Millennium Summit, the Johannesburg Declaration at the World Summit on Sustainable Development (2002), and the Delhi Declaration (2002) at the Eighth Conference of Parties (COP) to the UNFCCC.

These specific planning targets address many climate change concerns. For example, reduced poverty and hunger would enhance the adaptive capacity of the population. Reduced decadal population growth rates would lower GHG emissions, reduce pressure on land, resources, and ecosystems and provide higher access to social infrastructure. Increased reliance on hydro and renewable energy resources would reduce GHG and local pollutant emissions, enhance energy security and consequent economic benefits from lower fossil fuel imports, and provide access to water resources from additional hydro projects. The cleaning of major polluted rivers would result in enhanced adaptive capacity due to improved water, health and food security.

India's development priority envisages doubling the per capita income by 2012, reducing the poverty level by 10 per cent, providing gainful employment to all and ensuring food, energy, and economic security for the country. The Indian government has targeted an 8 per cent GDP growth rate per annum for 2002–2007. To achieve these development priorities, substantial additional energy consumption will be necessary and coal, being the abundant domestic energy resource, would continue to play a dominant role. The Indian targets indicate a developmental pathway for the country, different from the present baselines. Moreover, there are considerable costs associated with achieving these targets, requiring the commitment of

Table 6.1 Millennium development goals and related Indian plan targets

Millennium development goals and global targets[1]	India's tenth Plan (2002–2007) and beyond targets[2, 3, 4]
Goal 1: Eradicate extreme poverty and hunger.	
Target 1: Halve, between 1990 and 2015, the proportion of people whose income is less than $1 a day. ***Target 2:*** Halve, between 1990 and 2015, the proportion of people who suffer from hunger.	Double the per capita income by 2012. Reduction of poverty ratio by 5 % by 2007 and by 15 % by 2012. Reduce the decadal population growth rate to 16.2% between 2001-2011 (from 21.3% during 1991-2001).
Goal 2: Achieve universal primary education .	
Target 3: Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling.	All children to complete five years of schooling by 2007. Increase in literacy rates to 75% by 2007 (from 65% in 2001).
Goal 3: Promote gender equality and empower women.	
Target 4: Eliminate gender disparity in primary and secondary education, preferably by 2005, and in all levels of education, no later than 2015.	At least halve, between 2002 and 2007, gender gaps in literacy and wage rates.
Goal 4: Reduce child mortality.	
Target 5: Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate.	Reduction of Infant Mortality Rate (IMR) to 45 per 1000 live births by 2007 and to 28 by 2012 (115 in 1980, 70 in 2000).
Goal 5: Improve maternal health.	
Target 6: Reduce by three-quarters, between 1990 and 2015, the Maternal Mortality Ratio (MMR)	Reduction of MMR to 2 per 1000 live births by 2007 and to 1 by 2012 (from 3 in 2001).
Goal 6: Combat HIV/AIDS, malaria and other diseases.	
Target 7: Have halted by 2015 and begun to reverse the spread of HIV/AIDS. ***Target 8:*** Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases.	Have halted by 2007; 80 to 90% coverage of high-risk groups, schools, colleges and rural areas for awareness generation by 2007. 25% reduction in morbidity and mortality due to malaria by 2007 and 50% by 2010.
Goal 7: Ensure environmental sustainability.	
Target 9: Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources. ***Target 10:*** Halve by 2015 the proportion of people without sustainable access to safe drinking water. ***Target 11:*** Have achieved by 2020 a significant improvement in the lives of at least a 100 million slum dwellers.	Increase in forest and tree cover to 25% by 2007 and 33% by 2012 (from 23% in 2001). Sustained access to potable drinking water to all villages by 2007. Electrify 62,000 villages by 2007 through conventional grid expansion, the remaining 18,000 by 2012 through decentralized non-conventional sources like solar, wind, small hydro and biomass. Cleaning of all major polluted rivers by 2007 and other notified stretches by 2012. Expeditious reformulation of the fiscal management system to make it more appropriate for the changed context.

contd…

Millennium development goals and global targets[1]	India's tenth Plan (2002-2007) and beyond targets[2, 3, 4]
Goal 8: Develop a global partnership for development.	
Target 12: Develop further an open, rule-based, predictable, non-discriminatory trading and financial system (includes a commitment to good governance, development, and poverty reduction—both nationally and internationally). ***Target 16:*** In co-operation with developing countries, develop and implement strategies for decent and productive work for youth. ***Target 17:*** In co-operation with pharmaceutical companies, provide access to affordable essential drugs in developing countries. ***Target 18:*** In co-operation with the private sector, make available the benefits of new technologies, especially ICT's.	Tenth Plan includes state-wise break up of the broad developmental targets. Higher integration with the global economy. Create 50 million employment opportunities by 2007 and 100 million by 2012 (the current back-log of unemployment is around 9%, equivalent to 35 million people).

Note: Millennium Targets13 and 14 refer to special needs of least-developed, land-locked and small island countries. India is party to several international conventions and programmes assisting these countries. India is also implementing policies in line with Target 15 that exhorts amelioration of debt of developing countries, including own debt, under global cooperation.

Sources: [1] Human Development Report, UNDP, 2003.

[2] Tenth Five-Year Plan, Planning Commission, GOI, Vol. 1 (pp 6–8), Vol. 2 (pp. 108, 117, 909, 914, 927).

[3] For the most recent year between 1985–1999 (UNDP, 2002), pp. 176.

[4] India Vision 2020, SP Gupta Committee report, Planning Commission, GOI, 2002 (pp. 93).

additional resources from various sources, as well as by realigning new investments.

Market-oriented economic reforms initiated in the past decade have expanded the choice of policy instruments, technologies and resources. In the energy and electricity sectors, this has led to the amelioration of fuel quality, technology stocks, infrastructure, and operating practices. The concerns about rising energy, electricity and carbon intensity of the Indian economy inspired the Indian government to initiate targetted programmes and institutions to promote energy efficiency, energy conservation, and introduce renewable energy technologies. The thrust areas include energy efficiency improvement in all sectors of the economy, promoting hydro and renewable electricity, power sector reforms including national grid formulation and clean coal technologies for power generation, energy infrastructure development, coal washing, cleaner and less carbon-intensive transport fuel promotion, and environmental quality management.

Therefore, it is clear that the Indian planning process and global climate change concerns are intricately linked. Taking care of the national planning objectives would include addressing many of the climate change concerns.

DEVELOPMENT AND CLIMATE CHANGE

Climate change interfaces with diverse societal and natural processes and, consequently, with the development processes. Conventionally, climate change has been considered as an impediment to development and, conversely development is viewed as a threat to the climate. The development and climate paradigm, also alternatively referred to as 'development first', views development as the tool to address the challenges posed by climate change, the key to overcoming our vulnerability and enhancing our capabilities for adaptation to its adverse impacts. In this paradigm, the development itself—i.e., building capacities, institutions and human capital in developing countries—emerges as the key factor for enhancing adaptive and mitigative capacities.

The term 'development' refers to broader social goals, in addition to economic growth. In recent years, the national development policy perspective has taken a more inclusive view of the scope, content and the nature of national development. The conventional paradigm of economic development, which was woven around optimal resource allocation, is now extended to include participative processes, local initiatives and global interfaces. As mentioned earlier, the new vision views welfare as the *raison d'etre* of development. Under the emerging development perspective, while efficient resource allocation is best addressed by market mechanisms, the institutions are also considered as a key component for the optimal utilization of a nation's resources. Thus, the institutions and policies play a vital role in welfare development. The development vision duly recognizes the strong links between government policies, organizational capacity, and the results of social development. The vision also perceives the provision of resources for social services and the creation of new partnerships for the delivery of services as essential; it also accords primacy to the implementation of the vision within a framework of policies and institutions, which provide mechanisms for efficiency and accountability.

Many initiatives for adaptation and mitigation are likely to be integrated with and added to the already existing economic development projects. The financing for projects involves ensuring that the risks and expected returns are commensurate with the requirements of the financial markets; matching investors who have available funds with projects seeking funding is by no means easy in developing countries. The success of linking investors with projects, via appropriate sets of institutional and financial intermediaries, partly depends on the degree of development of the financial markets and the financial services sector in the country where the project will be implemented.

Therefore, the 'development first' perspective proposes to create myriad economic and social activities and orient these towards the climate-friendly pathway. Since the goals of sustainable national development are favourable to the issue of climate change, the achievement of these goals would accrue a double dividend in terms of added climate change benefits. The cascading effects of sustainable development would reduce emissions and moderate the adverse impacts of climate change, and thereby alleviate the resulting loss in welfare.

The vital relationship between sustainable development and climate change was brought into sharper focus in the Delhi Declaration made at COP-8 in November 2002. The Declaration reiterated the view of the World Summit on Sustainable Development that poverty eradication, changing unsustainable patterns of production and consumption, and protecting and managing the natural resource base of economic and social development are the overarching objectives of, and essential requirements for, sustainable development.

The WSSD emphasized the need to augment the financing of development and technology transfer to developing countries and the need for climate change policies to be aligned with national development priorities of nations. The Delhi Declaration also noted that technology transfer should be strengthened, through concrete projects and capacity building in all relevant sectors such as energy, transport, industry, health, agriculture, biodiversity, forestry and waste management. Technological advances should be promoted through research and development, economic diversification and by strengthening the relevant regional, national and local institutions for sustainable development.

CLIMATE-FRIENDLY INITIATIVES

India has the world's second largest population and fourth largest economy, with a per capita annual GDP of US $462 in 2001. India's economy grew at a rate of almost 6.6 per cent per year during the 1990s, nearly doubling over that time. The energy use grew even faster, at a rate close to 7 per cent. The demand for electric power has grown still faster, in the order of 8 % per year. Despite this growth, India's per capita electricity use averages at only one-sixth of the world average. Its per capita CO_2 emission also rank among the lowest in the world, averaging four per cent of the US per capita CO_2 emissions in 1994, eight per

Population control and family welfare policies have indirectly contributed to GHG emission abatement.

cent of Germany, nine per cent of UK, 10 per cent of Japan and 23 per cent of the global average.

To achieve the national developmental targets (Table 6.1), India endeavours to pursue a sustainable pathway with reduced population growth rates, an open market-based economy, and a sophisticated science and technology sector. It has also undertaken several response measures that contribute to the objectives of the UNFCCC.

The reduction in the decadal population growth rates of India over the last 30 years is a prominent policy initiative making a real, if indirect, contribution to controlling GHG emission growth from India. The government has many programmes that promote family planning and female literacy and advice against early marriages. However, the momentum of population growth will continue for a while, because the high Total Fertility Rates (TFR) in the past has resulted in a large proportion of the population being currently in their reproductive years. The higher fertility due to the unmet need for contraception (estimated contribution is 20 per cent) has led to 168 million eligible couples, of which just 44 per cent are currently effectively protected. The government aims to make contraception more widely accepted, available, accessible, and affordable for family planning, as well as to counter the spread of AIDS. The decadal population growth rate has steadily declined from 24.8 per cent during 1961–1971 to 21.3 per cent during 1991–2001 and is targetted to further decline to 16.2 per cent during 2001–2011. (Box 6.3).

Box 6.3: India's Demographic Achievements

Half a century after formulating the National Family Welfare Programme, India has:

- Reduced the Crude Birth Rate (CBR) from 40.8 (1951) to 24.8 (2001).
- Halved the IMR from 146 per 1000 live births (1951) to 70 per 1000 live births (2001).
- Quadrupled the Couple Protection Rate (CPR) from 10.4 % (1971) to 44 % (1999).
- Reduced the Crude Death Rate (CDR) from 25 (1951) to 8.9 (2001).
- Added 25 years to the average life expectancy from 37 years to 62 years.
- Achieved nearly universal awareness of the need for, and methods of, family planning.
- Reduced the Total Fertility Rate from 6.0 (1951) to 3.1 (2001).

Source: Census of India, 2001, Government of India.

This has resulted in reducing births by almost 40 million over the last 30 years, contributing to the reduction in emissions growth amounts to approximately 40 Mt of CO_2 per year currently, at about one tonne of CO_2 emissions per capita per year.

The wide-ranging reforms in the past decade have accelerated economic growth and lowered the barriers to efficiency. The energy and power sector reforms, for instance, have helped to enhance the technical and economic efficiency of energy use. The last few years have witnessed the introduction of landmark environmental measures that have targetted the cleansing of rivers, enhanced forestation, installed a significant capacity of renewable energy technologies and introduced the world's largest urban fleet of CNG vehicles in Delhi.

The recent National Highway Development Project to convert the existing roads into four/six-lane highways covering around 13,146 km of road network, with another 1,000 km of port and other connectivity, is expected to cost Rs 540 billion (US$ 11.8 billion). More than 2,100 km has already been completed over the last three years and another 5,000 km are under various stages of completion. More than US$ 3.5 billion have been spent and/or committed. The project

National Highway Development Project is an example of climate friendly development.

will result in substantial savings in fuel consumption and, therefore, in GHG emissions, with the total socioeconomic benefits estimated at Rs 80 billion per year for the golden quadrangle alone (http://www.nhai.org/, dated 6 April, 2004).

The national capital, Delhi, has recently started its first state-of-the-art metro railway to ease traffic congestion, reduce commuting time, save fuel, reduce local pollutants and GHG emissions, and increase the share of public transport in the mega city. It is planned to construct 68.3 km of metro rail tracks in Delhi by 2005, which will cost Rs 105 billion. A unique feature of the Delhi Metro is its integration with other modes of public transport, enabling the commuters to conveniently change from one mode to another. These

The Metro Rail in New Delhi uses state-of-the-art technology.

and similar measures, affirmed by the democratic and legislative processes, have been implemented by committing additional resources, as well as by realigning new investments. These deliberate actions, by consciously factoring in India's commitment to the UNFCCC, have redirected economic development to a more climate-friendly path.

India is endowed with diverse energy resources, wherein coal has a dominant share. Therefore, the Indian energy system evolved with a large share of coal in the energy consumption. This, coupled with the rising energy consumption, led to a rising carbon emissions trajectory in the past. However, India's per capita CO_2 emission of 0.87 t-CO_2 in 1994 is still amongst the lowest in the world. It is four per cent of the US per capita CO_2 emissions in 1994, eight per cent of Germany, nine per cent of UK, 10 per cent of Japan and 23 per cent of the global average. India's energy, power, and carbon intensities of the GDP have declined after the mid-nineties, due to factors such as increased share of service sector in the GDP, and energy efficiency improvements. India has also taken some initiatives to enhance penetration of low carbon-intensive fuels like natural gas and carbon-free sources like renewable energy.

Fossil energy

The concerns about rising energy, electricity and carbon intensity of the Indian economy led the Government to initiate targetted programmes and institutions to promote energy efficiency, conservation and introduction of renewable energy technologies. The thrust areas include cleaner coal mining and use, oil security, infrastructure development, environmental and quality management, reforms, power grid integration, and energy efficiency. The clean coal initiatives include improving the quality of coal and the productivity of coal mining; adopting environment-friendly technologies including coal gasification, beneficiation, and liquefaction for value addition to domestic coal. Other initiatives such as the Electricity Act (2003); renewable energy; increasing the share of large hydro projects in the generation-mix; reducing electricity T&D losses; labelling equipment and benchmarking for energy efficiency; energy saving targets for motors, lighting and energy-intensive industries; reduction in gas flaring; waste heat recovery; and dual-fuel engines,

REVA: The indigenously built electric car.

indicate the government's commitment to climate-friendly development.

Coal will continue to be the mainstay of commercial energy in India. The four-pronged strategy of more efficient and clean use of coal includes the rationalization of coal use, the participation of the private sector, price reforms, and technological up gradation. Some prominent technological interventions are in the areas of coal washing, combustion technologies and the recovery of coal-bed methane.

Energy conservation and efficiency enhancement measures in the oil sector include the reduction of gas flaring, waste heat recovery, energy audits, more efficient norms for road vehicles, and the substitution of diesel with natural gas. Institutions like the Petroleum Conservation Research Association have been promoting R&D activities for the development of fuel-efficient equipment and mass awareness.

The Ministry of Petroleum and Natural Gas has designed several programmes to mitigate the impact of activities in the oil and gas sector on the environment, which are listed below:

- It has embarked on the programme of exploiting coal-bed methane (CBM) by the oil sector, focusing on the methane trapped in the coal seams in mines that are economically unviable due to their depth, or are not safe. Under the CBM policy, 16 blocks have been awarded for exploration.
- Petrol and sulfur have been made more eco-friendly with the supply of unleaded petrol and low-sulfur petrol and diesel from 2000 onwards. The Euro-II equivalent fuel quality is available in selected urban areas and complete coverage would be achieved by 2005. The supply of Euro-III equivalent quality fuel is slated for commencement in selected major cities with effect from 1 April 2005.
- The government had also launched the programme of blending of five per cent ethanol in petrol in India. In the first phase, the major sugarcane-producing states have been selected for coverage and the remaining states are being taken up in the second phase in line with the availability of ethanol. The blending percentage would be raised to 10 per cent in subsequent phases.
- With the consumption of diesel being five times the consumption of petrol, the government had also considered blending of ethanol in diesel. However, in view of the inadequate quantity of ethanol as well as instability of the blend achieved, the blending of bio-diesel in diesel, like the developments abroad, is undergoing trials.
- To reduce the pressure on forests and the burning of biomass in rural areas, the government has introduced 5 kg LPG cylinders, available at affordable prices for the poorer sections of the population. The LPG waiting list has been liquidated and domestic LPG connections are now available across the counter.
- The laying of more gas, crude and product pipelines for transport of petroleum and gas products have been taken up, since this mode of transportation is the most eco-friendly and the least polluting. Simultaneously, the proposed national gas grid would serve to provide interconnectivity between consumers and producers in different parts of the country.
- The government has actively embarked on diplomatic initiatives with the countries of the Middle East and its immediate neighbours for the supply of natural gas, either as LNG or through pipeline transport, as the gases are environmentally cleaner than liquid petroleum fuels.
- CNG is being supplied for use as an auto fuel in Delhi and Mumbai and also as a domestic fuel. This auto fuel will be available in other cities, like Pune, Kanpur, Lucknow, Agra, Bareilly and

Faridabad, over the next two years.

- Auto LPG is also being supplied in the 10 most polluted cities of the country, with the commissioning of auto LPG dispensing stations in Agra, Ahmedabad, Bangalore, Chennai, Delhi, Hyderabad, Kanpur, Kolkata, Mumbai and Pune.
- The oil companies have also improved their housekeeping practices by systematic efforts to control gas flaring, recover waste heat, minimize handling losses, etc.
- Another environment-friendly measure proposed is the use of hydrogen for transportation purposes. Although work is still in the R&D stage, the Indian oil and gas sector has decided to step up activities in this area. The success of the move will go a long way in reducing GHG emissions, since hydrogen contains no CO_2, unlike hydrocarbons.

The government policy has included public investment to develop the natural gas infrastructure for port handling, long-distance and local distribution. One example is the HBJ 1,500-km, high-pressure gas pipeline from near Mumbai to the north of Delhi, which carries 4-5 billion cubic meters of gas from offshore production. A national gas grid is also in the planning stages. The share of gas in the power-generating capacity has risen to eight per cent from only two per cent ten years ago. LPG has almost completely replaced commercial coal and kerosene in urban households; public vehicles also have been converted to run on CNG. Box 6.4 indicates some of the major achievements in the Indian petroleum sector.

Box 6.4: Success Story in the Petroleum Sector

- Dismantling of Administrative Price Mechanism on 31 March, 2002.
- New Exploration Licensing Policy introduced and two rounds completed in record time.
- Refining capacity targets surpassed.
- Release of around 34 million new LPG connections, thereby liquidating the entire waiting list for new cooking gas connections in India.
- Secured equity oil abroad.
- Introduction of auto LPG and setting up of Motor Spirit-Ethanol blending projects in selected States.

Source: Tenth Plan Document, Planning Commission, 2002.

The concerns about rising energy intensity, electricity intensity and carbon intensity of the Indian economy led the government to initiate specific programs and set up institutions to promote energy efficiency, energy conservation and introduction of renewable energy technologies. The thrust areas include:

- Cleaner coal mining and coal use,
- Oil security,
- Infrastructure development,
- Management of Environmental quality,
- Power grid integration, and
- Energy efficiency improvement.

The clean coal initiatives include improving the quality of coal and the productivity of coal mining; adopting environment-friendly technologies including coal gasification, beneficiation, and liquefaction for value addition to domestic coal and other initiatives such as:

- renewable energy,
- increasing the share of large hydro projects in the generation-mix,
- reducing electricity T&D losses,
- labeling equipment and benchmarking for energy efficiency,
- energy saving targets for motors, lighting and energy- intensive industries,
- reduction in gas flaring,
- waste- heat recovery,
- dual-fuel engines, etc.

indicate the government's commitment to climate-friendly development.

The Indian electricity sector has long been carbon intensive and the largest source of carbon dioxide emissions. Natural gas has penetrated this market in recent years and helped to reduce the carbon intensity of electric power generation. The improvement in the combustion efficiency of conventional coal technologies, along with strong promotion of renewable technologies, has made appreciable contributions to reduced GHG emissions. The lower carbon emissions also have resulted from important technological advancements in coal washing. Recent government policy restricts the transportation of unwashed coal to less than a 1,000 km. The customers are motivated to reduce the ash content to improve efficiency, reduce local pollution, and cut freight costs. The capture of coal bed methane (which is a greenhouse gas) is being promoted for use as clean fuel. New combustion technologies, including super-critical coal-fired power plants, are being introduced as described below:

Introduction of Super-critical Technology: In order to achieve higher operational efficiency and minimize environmental impact, NTPC is introducing super-critical technology in the country in the forthcoming mega projects. Switching from sub-critical to super-critical technology results in enhancing the efficiency of thermal conversion, thereby reducing fuel consumption and consequently emissions.

Integrated Gasification Combined Cycle (IGCC): Lately, coal gasification-based power generation has emerged as an environmentally attractive generation alternative; i.e., high efficiency and low emissions. A detailed technical and economic feasibility study report for setting up a 100 MW IGCC Plant based on Indian coal at NTPC Dadri is in progress. Also, NTPC and BHEL are collaborating for setting up a 100 MW IGCC demonstration plant based on Indian coal at NTPC Auraiya plant.

Renewable energy

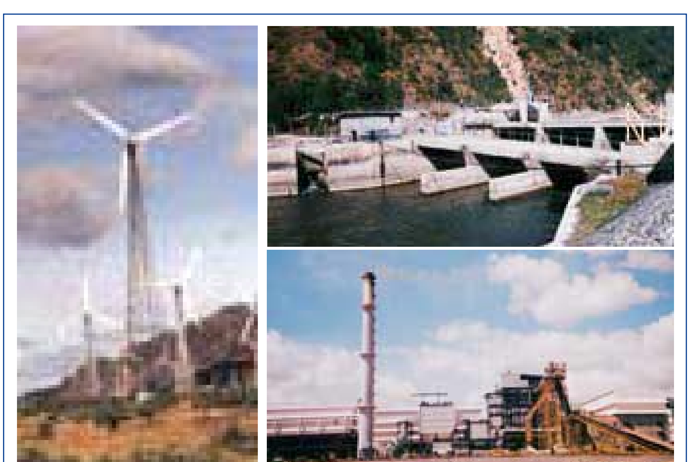
India has one of the most active renewable energy programmes in the world, which has a wide geographical reach and covers diverse economic sectors. In the rural areas, over 3.26 million biogas plants and 34.3 million improved wood-burning stoves have been installed. So far about 3,50,000 solar lanterns, 177,000 home-lighting systems, 41,400 street-lighting systems, 1.17 MW aggregate capacity of small and stand-alone power plants, and over 4,200 solar-pumping systems have also been installed.

The recent years have seen a significant increase in renewable energy applications for electricity generation. Ministry of Power has taken various steps to improve the hydropower development in India. These mainly include additional budgetary financial support, R&M and up-rating of existing hydro stations, basin wise hydropower development and comprehensive ranking studies for 399 hydro schemes. As on December 2003, hydro electric projects of 27,760 MW have been commissioned and are in operation. 41 schemes with an aggregate installed capacity of 15,300 MW (which includes capacity scheduled to be commissioned during 2007-2012) are in different stages of implementation. During 2002-2007, hydro capacity addition planned is 14,393 MW. To meet future power requirements, hydro electric schemes with a total installed capacity of about 20,000 MW are planned to be implemented.

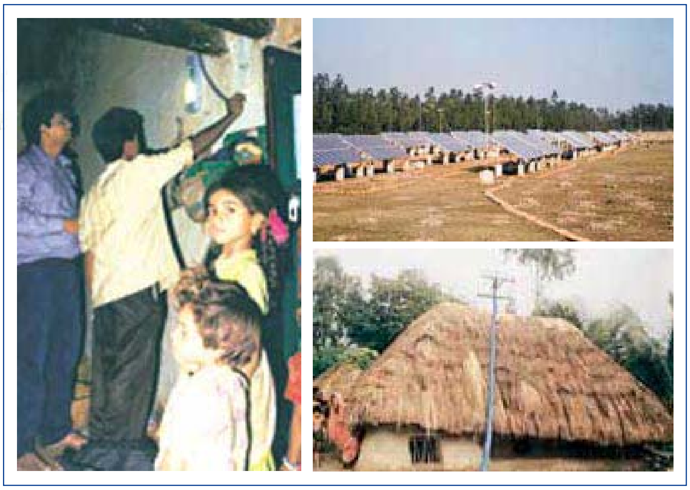
Recently, a 50,000 MW hydro electric initiative has been launched that includes preparation of feasibility reports for 162 hydro electric schemes planned for execution during 2012-2017.

The total installed capacity of small hydro-power projects (up to 25 MW) is 1529 MW presently.

Solar Photovoltaic (SPV) power systems are being used for a variety of decentralized applications, such as rural electrification (Box 6.5), railway signaling, microwave repeaters, TV transmitters, telecommunications, and for



India has one of the most active renewable energy programmes in the world.



Solar power lights rural India.

providing power to border outposts. Biomass power-generation plants, aggregating to 537 MW have been installed in the country. In addition, biomass gasification systems totaling 55 MW capacity have also been set up for decentralized energy applications. A 140 MW Integrated Solar Combined Cycle (ISCC) Power Project is being set up, which is one of its kind in the world, based on naphtha fuel and solar power.

India's installed capacity of 1507 MW places it among the first five countries in the world in the field of wind-power generation. Wind generators of 250 kW to 600 kW capacities are being manufactured in the country.

Box 6.5: Solar Energy Lights Rural India

SELCO India, a private sector company established in 1995, has installed over 25,000 Solar Home Systems (SHS), 600 solar streetlights and 4,000 solar thermal systems, mostly in rural India. These initiatives have been successful by coupling quality products and after- sales service with doorstep customer financing at priority sector lending rates through several regional rural banking institutions. The company has also sold over US$ 50,000 worth of carbon credits to US and European firms for these clean energy initiatives.

The total installed capacity of small hydropower projects (up to 25 MW) is 1406 MW. Some projects with an aggregate capacity of about 15.21 MW have also been completed in the areas of energy recovery from urban, municipal and industrial waste.

Ministry of Power has recently launched Rural Electricity Supply Technology (REST) mission for providing affordable and reliable power supply to rural and remote areas through decentralized distributed generation based on renewable energy resources such as solar, mini- and micro-hydro, biomass, etc.

Energy efficiency and conservation

India's elasticity of energy consumption was more than unity for the 1953–2001 period. However, the elasticity for primary commercial energy consumption for the 1991–2000 period is less than unity. This could be attributed to several factors, such as the improvement in efficiency of energy use and the consequent lowering of the overall energy intensity of the economy, and the higher share of hydrocarbons in the overall energy mix.

Energy conservation is accorded high priority by the central and state governments through multiple measures to improve the energy management of the demand and supply side. These include energy standards, labelling equipment and appliances, energy codes for building, energy audits, energy efficient bulbs, tubelights and agricultural pumpsets, mass awareness and extension efforts. In addition, affordable alternative energy sources can greatly influence the pattern of energy consumption and lead to energy efficiency. The Tenth Five-Year Plan provides energy saving potential for the country from some specific activities (Table 6.3).

The NTPC, the premier power generation company in India working under Ministry of Power, has achieved the ISO: 14001 Standard for all the stations it owns and one more that it manages. In addition, the NTPC has obtained ISO 14001 accreditation for

Table 6.3: Energy saving potential

End-use type	Potential Energy Savings (GWh)
Motors and drive systems (Industry and agriculture sector)	80000
Lighting (domestic, commercial and industrial sector)	10000
Energy intensive industries	5000
TOTAL	**95000**

Source: Tenth Plan Document, Planning Commission, 2002.

its Corporate Environment Management Group and Ash Utilization Division.

The best Operation and Maintenance (O&M) philosophy of the NTPC has yielded substantial efficiency and environmental improvement. The O&M practices of NTPC have immensely benefitted old stations taken over by NTPC, which were operating at a lower efficiency earlier. In order to increase the efficiency of ESP on a sustained basis, new technologies such as water-fogging, and sodium conditioning, are under trial to further reduce particulate emissions in some stations. The NTPC has taken a proactive step with respect to the reduction of GHGs and is in the process of preparing a road map for CO_2 sequestration.

The Indian government passed the Energy Conservation Act in 2001, which mandates the setting up of a Bureau of Energy Efficiency (BEE) that will introduce stringent energy conservation norms for energy generation, supply and consumption. However, the enforcement of penalties stipulated in the Act have been kept in abeyance for five years, during which time people would be made aware of the economics and efficacy of the conservation of energy.

Industrial development has contributed significantly to economic growth in India, with indigenous coal accounting for over half of total primary energy consumption. Industrial energy intensity has declined gradually over the past decade, mainly due to the adoption of new and efficient technologies and rapid expansion of non energy-intensive industries.

Transport

There has been a sweeping change in India's vehicle stock over the past decade. Economic reforms have enlarged the vehicle market and prompted rapid penetration by Indian-collaborated foreign brands. The rising concern about air quality prompted the introduction of emissions-limiting performance standards in 2000. European-level emission norms for new cars and passenger vehicles were introduced in 2002 in Delhi, Mumbai, Chennai, and Kolkata. Apart from mitigating local pollutants, the vehicles meeting these norms are more energy efficient and emit fewer GHGs, while providing the same level of service.

In Delhi, 84,000 public vehicles—all buses, taxis, and three-wheelers—were converted from gasoline and diesel to CNG. This rapid achievement was accomplished in about one year to comply with the clean air laws. Although the compliance cost per vehicle was relatively high—up to US $300 for a three-wheeler and US $1,000 for a car—the policy has been applied uniformly and effectively. The Government of India has recently announced an Auto Fuel Policy for the country to ensure cleaner air for the citizens through efficient vehicles, cleaner fuels and other solutions that may also reduce carbon emissions.

Agriculture

Some of the climate-friendly initiatives in the agriculture sector include the standardization of fuel-efficient irrigation pump-sets, retrofitting existing pump-sets for higher energy efficiency, better water and crop management, improved cultivars, more efficient application of synthetic fertilizers, enhanced organic fertilizer use, improved animal feeds and digesters, and rationalization of power tariffs for the agriculture sector. Many of these measures would serve to reduce CO_2, methane and N_2O emissions.

Residential

The development and promotion of fuel-efficient equipment and appliances like kerosene and LPG stoves, compact fluorescent lamps, and better pumps for water lifting in high-rise buildings are endorsed in the residential sector.

Increased mechanization in Indian agriculture

Afforestation and Land Restoration

The forest and tree cover constitutes above 23 per cent of the country's geographical area according to the 2001 estimates. The per capita deforestation rate in India is amongst the lowest in the major tropical countries. The area of forests with 40 per cent crown cover has been increasing. A major afforestation plan is being implemented with the assistance of local population through JFM. The basic components of India's forest conservation efforts include putting a check on the diversion of forest land for non-forestry purposes; encouragement of farm forestry/private area plantations for meeting industrial wood requirement; expansion of the area under the protected area network; and control of forest fires. During 1990-1999, an area of over 14 Mha was brought under various afforestation programmes.

The NTPC and other central power sector undertakings of the Government of India are adopting afforestation and other environmental measures to enhance CO_2 removals by natural sinks. These include investments to increase the national forest cover, extensive afforestation and greenbelt development, and compensatory afforestation for projects that destroy forestlands.

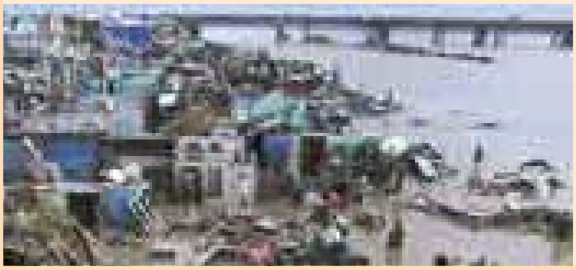
The NTPC has already planted more than 15 million trees in and around its power stations. The scientific selection of species planted contributes to aesthetic improvement and serves as a sink for pollutants including CO_2. The NTPC has introduced medicinal and bio-diesel plants in its plantation programme. Further, the filled-in abandoned ash disposal areas are being reclaimed and restored. A Special Purpose Vehicle (SPV) for afforestation has been registered as a society for increasing the forest cover and for the natural sequestration of CO_2.

The National Forest Policy envisages peoples' participation in the development of degraded forests, to meet their requirements of fuelwood, fodder and timber, as well as to develop the forests for improving the environment through JFM. As on 1 September, 2000, 10.25 Mha of forestland has been brought under the scheme and 36,165 Village Forest Committees have been constituted. The protected area network includes 88 National Parks and 490 Wildlife Sanctuaries and is spread over 14.8 Mha. The conservation of fragile ecosystems has been accorded a high priority. There are 12 biosphere reserves that have been set up in the country with the aim of protecting the representative ecosystem. Management plans are being implemented with respect to over 20 wetlands in the country, mangroves and coral reefs. The National Wasteland Development Board has been entrusted with the responsibility of regenerating degraded and non-forest and private lands. The National Afforestation and Eco-Development Board is responsible for regenerating degraded forestlands, the land adjoining forest areas, and ecologically fragile areas. These planned measures have led to a steady increase in the rate of afforestation, significantly contributing to climate change.

Various planned responses in India have led to sizeable savings in carbon emissions during the past decade. The process has helped to integrate the national development policies with the objectives of the UNFCCC. The additional CO_2 emissions saved over the past decade by promoting renewable energy and energy conservation initiatives amount to over 330 Mt and another 40 Mt from population policies. These initiatives and additional investments have altered India's emissions trajectory, making national development more climate friendly.

Chapter 7

Constraints and Gaps, and Related Financial, Technical and Capacity Needs



Constraints and Gaps, and Related Financial, Technical and Capacity Needs

Chapter 7

This chapter, in accordance with national circumstances and development priorities, describes constraints and gaps, and related financial, technical and capacity needs, as well as proposed activities for overcoming the gaps and constraints associated with the implementation of activities and programmes envisaged under the UNFCCC . This chapter also includes some climate change projects. The coverage is not an exhaustive elucidation of India's financial and technological needs and constraints, and these have been identified during the implementation of the enabling activity for the Initial National Communication. With more scientific understanding and increasing awareness, further areas of work could also be identified, including the continuing need for improving the quality of national GHG inventories, regional and sectoral assessment of vulnerabilities and adaptation responses, and communication of information on a continuous basis.

The broad participatory approach adopted for preparing India's Initial National Communication has contributed to understanding the challenges for addressing climate change concerns in India, while simultaneously building capacity in diverse disciplines, such as inventory estimation, emission coefficient measurements, quantitative vulnerability assessment, and inventory data management.

NEED FOR CONTINUOUS REPORTING

Present efforts in inventory estimation

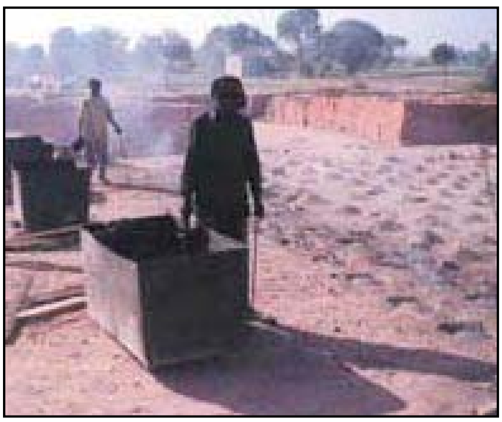
The GHG emissions inventory for non-annex I countries is to be reported to the UNFCCC Secretariat as per 10/CP.2 guidelines for the Initial National Communications. These guidelines have been improved and were adopted during the COP-8 at New Delhi in October 2002. GHG inventory reporting requires detailed activity data collection and estimation of country-specific emission coefficients. The level of inventory reporting depends on the data quality and methodology employed and is indicated as Tier I, II or III, as per the Revised 1996 IPCC Guidelines for Greenhouse Gas Inventories. Despite the comprehensive initiation of activities under the Initial National Communication project, there is considerable scope for further improvement. The inventory estimation has to be made at a more disaggregated level, preferably at a Tier II or III levels for most of the sectors, resolving the differences between top-down and bottom-up estimates. Finer sub-sectoral level estimates for activity data and EF have to be developed. Similar and consistent formats have to be adopted for data reporting and consistency by organizations generating activity data. The major constraints and gaps in Indian GHG inventory estimation are now presented.

Non-availability of relevant data

This is a prominent concern, especially in developing countries where time series data required for GHG inventory estimation is not available for some specific inventory sub-categories. For example, in the waste sector, details about annual municipal solid waste generation, collection, dumping and dumpsite characteristics are not available beyond five to 10 years for even the large metropolitan cities; while for smaller cities, the data availability is poor . This data is required for methane emission estimation. In absence of this data, the available time series information is extrapolated for a city, or that from a few cities extrapolated for the entire country, based on homogeneous city classifications.

Another constraint is the non-availability of data for informal and less organized sectors of the economy. These include agriculture, forestry and many small-

Energy consumption data in unorganised sectors and small scale industries, such as sugar, ceramics and brick, require refinement.



scale industries (SSI) like brick, sugar, glass and ceramics, dyes, rubber, plastic, chemical and engineering products. The SSI sector in India comprises modern and traditional industries encompassing the continuum of the artisans and handicrafts units at one end and modern production units producing a wide range of around 7,500 products. Many of these industries, along with domestic and commercial sectors, are informal as far as energy accounting is concerned.

Similarly, improvements in activity data for various sub-categories of agriculture-related GHG emissions are critical. The key activity data include livestock population, synthetic fertilizer application, areas under different water regimes for rice paddy cultivation, and agriculture crop residue generation for various crops. Under the LULUCF sector; the area under different land-use categories, above-ground biomass and mean annual increment, soil carbon density, fuelwood and commercial timber consumption, have considerable uncertainty.

The National GHG inventory preparation is a continuous process of improving the reliability and consistency of inventory assessments. The Indian GHG inventory for the Initial National Communication has been mostly reported using Tier 1 and 2 approaches . As India plans to move to higher tier and more detailed inventory assessments in subsequent communications, the data gaps have to be identified and corrective action taken. Since the GHG inventory-reporting year lags behind the year of assessment by about four to five years for developing countries, the above data has to be generated now for use in subsequent national communications. This requires sustained commitment of resources and setting up of appropriate institutional frameworks.

Data non-accessibility

This is yet another peculiar data problem in developing countries. Since data collection requires considerable effort and resources, it is often treated as proprietary. Moreover, some of the data required for refining inventories to the Tier III level is considered confidential by the respective firms and not easily accessible. These firms have to be therefore sensitized about data needs for inventory reporting and refinement. Systems have to be devised for the regular publication of relevant information in desired formats for national GHG inventory estimation.

Another issue is the non-availability of data in electronic form. However, due to the increased penetration of computers and information technology, more data is becoming electronically available.

Data organization constraints

The different levels of GHG inventory reporting, called Tiers, require different data quality . Although data required for initial levels is already in the public domain through the annual reports and data statistics of various ministries and departments of the Government of India, it is not organized in desired formats. This requires considerable data organization, consistency checks and data management.

There is also inconsistency in some data sets released by the central and state governments for some activity data . Coal consumption by power plants is one such example, where the top-down data on gross national coal consumption and plant-level bottom-up coal consumption data from separate reports of different ministries do not converge to the same number. The reasons may be due to aggregation errors, and/or inaccuracies in supply side reporting of coal off-take by the power sector versus the demand side reporting of coal consumption by individual power plants.

Another gap area is that the sectoral data for various fuels do not match across different ministry reports in a few instances. Although many of the industries are reasonably well organized, however, accounting of all their energy resources is not widely available. For example, the Ministry of Petroleum and Natural Gas reports the consumption of major petroleum products like diesel, furnace oil, and low sulphur heavy stock (LSHS) for engineering, aluminium, ceramic and glass, chemical industries, mining and quarrying (MoPNG, 1994-1995). However, the Coal Directory of India does not indicate coal consumed by these industries separately (MoC, 1996). Therefore, energy consumption for these industries cannot be provided for all the energy resources. Thus, for consistent energy consumption accounting and reporting purposes, many industries have to be combined together as 'Other Industries'. The final inventory reporting is determined by the least common factors of reporting and therefore, limits detailed representation.

The sectoral definitions for different fuels may not be consistent even in the same ministry document. For example, the national consumption of LSHS is combined and reported together for the entire transport sector, while for diesel consumption, separate data for road, aviation, shipping, railways and other transport is provided (MoPNG, 1999-2000). Therefore, for inventory estimation and reporting purposes, either the LSHS data is to be distributed exogenously among various transport sub-sectors based on some indicators, or inventory reporting is to be done at the gross transport sector level only.

Development of representative emission coefficients

To capture Indian national circumstances, a beginning has been made to generate India-specific emission coefficients by undertaking in-situ measurements in some key source categories to try and define the range in uncertainties in the estimates through statistical methods. However, time and budgetary resources available under the project constrained the coverage under this activity. For uncertainty reduction in GHG emissions, India needs to undertake in-situ measurements for many more activities to capture the Indian realities. The sample size has to be statistically determined for all the categories covered under the National Communication , for instance, GHG emissions from power plants. Some critical gap areas covering the key source categories for Indian GHG emissions are as follows :

- Measurement of GHG emission coefficients from power plants.
- Measurement of GHG emission coefficients from steel plants.
- Measurement of GHG emission coefficients from cement plants.
- Measurement of GHG emission coefficients from petroleum refineries.
- Measurement of GHG emission coefficients for the road transport sector.
- Methane emission coefficient measurements from coalmines.
- Methane emission coefficient measurement from oil and natural gas venting, flaring and transport.
- GHG emission coefficient measurements from fully/partially informal energy intensive sectors, such as brick manufacturing, sugar and ceramics .

- Methane emission coefficients from municipal solid waste (MSW) sites.
- Methane emission coefficients from waste water (industrial and domestic).
- GHG emission coefficient measurements from industrial processes like lime production and use, nitric acid production, aluminium production, soda ash use, pulp and paper production.
- Measurements for the LULUCF sector, including rate of above-ground biomass (AGB) growth for different forest types, woody biomass volume for different forest types , land-use change matrix, and soil carbon density in Indian forests on a fine gridded scale.
- GHG emission measurements and activity data assessment for biomass used for energy purposes.
- Measurement of methane emissions from enteric fermentation for different livestock categories and age groups.
- Measurement of methane and N_2O from manure management.
- Measurement of N_2O emission coefficients from different rice paddy systems.
- Measurement/ estimation of GHG emission coefficients (especially N_2O) for different types of soils in India.

These activities require significant additional scientific work requiring considerable resources. Technical capacity has to be built at more institutions to conduct these in-situ measurements. Instrumentation upgradation and process accrediting has to be done for many existing laboratories.

Needs for GHG inventory estimation on a continuous basis

The GHG inventory estimation needs may be estimated at three levels:

- Data needs.
- Capacity development and enhancement needs.
- Institutional networking and coordination needs.

The data needs are based on the data gaps and constraints (Table 7.1). These include designing consistent data reporting formats for continuous GHG inventory reporting, collecting data for formal and informal sectors of the economy, enhancing data quality to move to a higher tier of inventory reporting, and conducting detailed measurements for India-specific emission coefficients. Capacity development has to be at two levels: institutions and individual researchers. Institutional capacity development requires financial support, technological support, instrumentation, and networking. Individual researcher capacity development is required to sensitize and train data generating teams in various sectors and at different institutions about the GHG inventory estimation process, so that researchers would be better equipped to collect and report the desired data on a continuous basis. Institutional networking and coordination is a critical factor for establishing new data frameworks and reporting formats in various sectors. The Initial National Communication project has contributed to initiate this process in India at various levels. However, sustained and timely financial and technological support are critical to sustain and strengthen this process.

LULUCF sector constraints and needs

The LULUCF sector in India has the potential to be a major source or sink of CO_2 in the future. The uncertainty in the estimates of inventory in the LULUCF sector is shown to be higher than other sectors, such as energy transformation, transportation, industrial processes and agriculture. The availability and access to information on activity data, emission coefficients and even sequestration rates in the LULUCF sector in India is limited and the uncertainty of the data is high, as in most countries. Thus, there is a need for improvement in the information generation processes for the inventory, to reduce the uncertainty involved in the estimation of GHG inventory in the LULUCF sector.

Inventory in the LULUCF sector requires activity data on area under different forest types and the area subjected to land-use change as well as the changes in carbon stocks of different land-use categories or forest types. The data needs and features are given in Table 7.2.

Status of data and uncertainty involved: Reliable and consistent GHG inventory requires activity data and emission or sequestration factors for various land-use categories in the country. However, uncertainty in the reliability and quality of activity data and emission factors in the LULUCF sector is high in all countries,

Table 7.1: Constraints and gaps in GHG inventory estimation

Gaps and constraints	Description	Potential measures (examples)
Data organization	Published data not available in IPCC-friendly formats for inventory reporting	Design consistent reporting formats
	Inconsistency in top-down and bottom-up data sets for same activities	Data collection consistency required
	Mismatch in sectoral details across different published documents	Design consistent reporting formats
Non-availability of relevant data	Time series data for some specific inventory sub-categories, e.g., municipal solid waste sites	Generate relevant data sets
	Data for informal sectors of economy	Conduct data surveys
	Data for refining inventory to higher tier levels	Data depths to be improved
Non-accessibility of data	Proprietary data for inventory reporting at Tier III level	Involve industry and monitoring institutions
	Data not in electronic formats	Identify critical datasets and digitize
	Lack of institutional arrangements for data sharing	Establish protocols
	Time delays in data access	Awareness generation
Technical and institutional capacity needs	Training the activity data generating institutions in GHG inventory methodologies and data formats	Arrange extensive training programmes
	Institutionalize linkages of inventory estimation with broader perspectives of climate change research	Wider dissemination activities
Non-representative emission coefficients	Inadequate sample size for representative emission coefficient measurements in many sub-sectors	Conduct more measurements
Limited resources to sustain national communication efforts	Sustain and enhance research networks established under Initial National Communication	Global Environment Facility (GEF)/ international funding
	India-specific emission coefficients	Conduct adequate sample measurements for key source categories
	Vulnerability assessment and adaptation	Sectoral and sub-regional impact scenario generation, layered data generation and organization, modelling efforts, case studies for most vulnerable regions
	Data centre and website	National centre to be established

particularly in developing countries.

i) Area under different land-use categories and area subjected to change:

Source: The FSI provides area under forest, and under different tree crown density classes at a frequency of two years. Area under agriculture and other land-use categories is provided by MOA.

Status of data: Availability of activity data according to forest and plantation types is limited. Currently, only the aggregate area under different tree crown densities is published, which is inadequate for inventory purposes. Changes or conversion of different forest and plantation types and grassland categories is not available.

Uncertainty: Uncertainty is high due to lack of data

Table 7.2: Data needs for GHG inventory in the LULUCF sector.

Activity Data		**Emission Factor/Sequestration Rate**	
Data needs	**Details**	**Data needs**	**Details**
Area under different land categories	Forest types Plantation types Trees outside forests Agricultural land	Above ground biomass (AGB)	Forest types Plantation types
Land-use change; Area under different forest types, subjected to change	Land converted to forest Conversion of forest and grassland to other categories	Mean annual AGB growth rate	Plantation types Regenerating abandoned land
Managed area abandoned	Subjected to regeneration Traditional and commercial	Soil carbon density	Native land types (forests, etc.) Agricultural land Pasture land Other land categories At different periods, for instance, over 20 years
Fuelwood consumption	fuelwood consumption Source of fuelwood		
Commercial timber consumption	Proportion coming from forest conversion and extraction from existing factors		

on area under different forest and plantation types as well as the area subjected to conversion according to these categories.

Limitations and barriers: The area under forests, according to tree crown densities is currently monitored at a frequency of two years. Expanding this to forest or plantation types requires large ground truthing. Lack of technical manpower and financial support is the key barrier to monitoring area as well as changes or conversion according to forest or plantation types.

ii) AGB and mean annual increment: This data is required for different forest or plantation types and managed land, both abandoned and regenerating.

Source: Forest inventory, silvicultural studies, field ecological research studies and plantation companies.

Status of data: The FSI has estimated the AGB for 22 forest strata, based on forest inventory. This data is available only for one-period. The estimates of Mean Annual Increment (MAI), which are based on the measurement of AGB at two periods is lacking. The MAI is available only for some forest types in published field research studies.

Uncertainty: Uncertainty of estimates of AGB is high due to:

- absence of periodic forest inventories
- absence of measurements of AGB according to different forest or plantation types at a disaggregated level
- absence of AGB measurements from the same plot at two time periods, close to the inventory year
- absence of permanent plots for frequent and periodic measurements and monitoring.

Limitations and barriers: Monitoring of AGB, for instance a frequency of five years, requires establishment of a large number of permanent inventory plots in each forest or plantation. India does not have periodic forest inventory plots and measurements due to financial and institutional barriers.

iii) Soil carbon density: is required for different native land-use categories before they are subjected to conversion as well as after conversion to a new land use category.

Source: Soil carbon density data is being estimated by the National Bureau of Soil Survey and Land Use

Planning (NBSSLUP), largely for non-forest land use categories. The only source of data on soil carbon density is the large number of research studies carried out in some forest types in India.

Status of data: Soil carbon density data is not available for all the forest and non-forest land use categories for the top 30 cm. Further, its availability is limited to only one time period.

Uncertainty: Uncertainty in soil carbon density data is high due to:

- absence of data for all forest and non-forest land-use categories
- absence of data at two time periods and over 20 year period in land categories subjected to land-use change.

Limitations and barriers: The forest inventory studies do not incorporate the measurement of soil carbon density. There is no specialized agency for monitoring soil carbon density in forest land-use categories. Forest departments are inadequately equipped to conduct soil carbon studies.

***iv) Fuelwood and commercial timber consumption*:** GHG inventory in the LULUCF sector requires data on the quantity of traditional and commercial fuelwood and timber consumption, and the proportion of wood coming from forest clearing and from extraction in the existing forests.

Source: The sources of data on consumption include forest department statistics as well as the national-level fuelwood consumption studies, carried out in the past. The source of timber consumption is the forest department as well as the FSI.

Status of data and uncertainty: Fuelwood and commercial roundwood consumption data is not available for the inventory year, particularly the proportion coming from forest clearing and extraction from existing forests and non-forest trees. Thus, the uncertainty is high.

Limitations and barriers: India does not have any programme to monitor the consumption of fuelwood and commercial roundwood periodically. There is no dedicated institution to monitor the extraction of fuelwood and commercial roundwood from forest and non-forest sources.

Existing institutions and capacity for generating data in the forest sector: The main sources of data for inventory in the forest sector are the forest departments, FSI and research institutions.

i) Forest area monitoring: The FSI is a dedicated institution under the MoEF for periodically monitoring the changing situation of land and forest resources and presents the data for national planning, conservation and management of environmental preservation and implementation of forestry projects at the national and state level. The FSI has regional offices in different parts of India, and has monitored the area under forests using remote-sensing techniques at a scale of 1:250,000 since 1987 to 1999. During 2000, a 1: 50,000 scale has been adopted for interpretation. The FSI does not have adequate resources and technical manpower to conduct periodic forest inventories.

ii) AGB and mean annual increment: The FSI has instituted a programme to conduct, periodic forest inventories in a limited number of locations. Currently, the main source of data on MAI as well as AGB is from studies conducted by universities and research institutions. There is no dedicated institution to periodically monitor the AGB and MAI.

iii) Soil carbon density: The NBSSLUP is a large national institution with regional centres for preparing soil maps and for estimating soil organic carbon in a large number of grids. The focus of the preparation of soil maps and estimates of different soil characteristics is largely limited to non-forest land use categories. A national level digitized soil carbon map has been prepared by NBSSLUP, but not accessible for research.

iv) Fuelwood and commercial roundwood consumption: India does not have any dedicated institution to estimate the consumption of fuelwood and commercial wood or their source.

Technology, capacity development and financial needs: India is a large developing country with a large forest-dependent population and thus, there is a need to monitor the status of forests, area, biodiversity, biomass stock, soil carbon and biomass extraction. India will have to initiate a dedicated forest inventory as well as GHG inventory programme to generate information and data needed. However, there are technical, institutional and financial barriers in establishing a dedicated forest and GHG inventory programme. This involves identifying existing or establishing new institutions, infrastructure and capacity development, and provision of adequate financial resources.

- *Technology needs:* India has to adopt advanced forest inventory, soil carbon density change monitoring and biomass extraction and utilization monitoring programmes.
- *Enlarged and periodic inventory*: The forest inventory should include long-term inventory plots for the estimation of AGB, below-ground biomass (BGB), litter, soil carbon pools and dead organic matter. There is a need to use remote-sensing techniques to monitor AGB changes, in addition to traditional forest inventory techniques.
- *Monitoring of forest area and changes*: The existing programmes of the FSI need to be enlarged to monitor the area changes according to forest or plantation types. There is also a need to generate a land-use change matrix describing the flows or changes from one category to another. This requires the strengthening of satellite monitoring system, as well as computation and interpretation facilities at FSI and regional centres of FSI.
- *Fuelwood and commercial roundwood consumption studies*: India has to establish a national sample survey programme for periodically monitoring fuelwood, industrial wood and sawn wood consumption in households, establishments and industries. This requires scientific sampling methods, data collection formats, data entry frameworks and analysis techniques.
- *Modelling;* tools and techniques are required for the following studies:
  - Projecting AGB stock and MAI for the inventory year and for future projections based on data from two inventory periods
  - Projecting soil carbon changes with land-use change over different periods
  - Projecting fuelwood and commercial roundwood consumption at the national level, based on sample studies.

***v) Capacity and institutional needs*: ** India has established institutions for undertaking the monitoring of forest area changes, forest inventory and soil organic carbon changes. India also has the Indian Council for Forestry Research and Education (ICFRE) and several other institutions, dedicated to training and research. However, all these institutions need additional capacity development to address the needs of GHG inventory estimation on a continuous basis.

- There is a need to undertake monitoring of forest area changes at aggregate and disaggregate levels, such as national or state forest types. This would require additional human resource for ground truthing periodically, computing and interpretational facilities.
- The GHG inventory in the LULUCF sector requires systematic and periodic forest inventory, incorporating additional parameter measurements such as: BGB, soil carbon and litter. Forest departments in different states will have to carry out the forest inventory for generating data required for GHG inventory at the national level. Thus, there is a need for enhancing the human capacity and training of field personnel, as well as staff for synthesis and periodic reporting.
- In India, the soil carbon status is being monitored by the NBSSLUP. However, since this institution does not focus on forest lands, there is a need for a dedicated institution to set up permanent plots for periodically monitoring soil carbon changes under different forest land-use systems as well as those that are subjected to change. Regional centres may also have to be set up to periodically monitor and report soil carbon changes.
- The National Sample Survey (NSS) is currently a large institutional system, aimed at monitoring social, financial, economic and other data. The NSS could be strengthened to incorporate the monitoring of fuelwood and commercial roundwood consumption in households, establishments and industry.

Vulnerability assessment and adaptation

The six critical priorities of the Indian planning process are:

- Economic security
- Energy security

- Environmental security
- Water security
- Food security, and
- Provision of shelter and health for all.

Climate change would impact all of these in varying degrees. Linking of these priority concerns with climate change policies is the key to harmonizing sustainable development and climate change actions. Research has been initiated under the Initial National Communication project to assess the potential impacts of climate change on some of these concerns, such as Indian agriculture, water resources, forestry, coastal zones, natural ecosystems, human health, industry and infrastructure, including the construction of consistent climate change scenarios for India and the assessment of extreme events using existing models and expertize. The work involves assimilation of existing research work, identification of vulnerable sectors and areas, and a few specific case studies for each sector. Time and budgetary resources available under the project constrained the coverage and in-depth sectoral impact assessment studies under this activity. The lack of data and national databases, resource scarcity, sub-regional and sectoral impact assessment scenarios, lack of modelling efforts and trained manpower, and limited national and regional networking of institutes and researchers, constitute some of the constraints.

The key tasks to address vulnerability and adaptation may be viewed in the matrix of strategies and geographic hierarchy (Table 7.3). Climate change is a long-term issue, i.e., the change in climatic parameters and their impacts would continue to exacerbate over decades and centuries. Therefore, the type and intensity of interventions would enhance with the expiry of time.

Research and systematic observation

Weather, climate and oceanographic research

The main thrust for Indian atmospheric and oceanographic research is committed to enhance the knowledge of the Asian summer monsoon under various objectives viz. the climate modelling, monsoon studies, climatic tele-connections,

Table 7.3: Key tasks for addressing vulnerability and adaptation needs.

Geographic Hierarchy	Local	National	Regional/ Global
Strategies			
Capacity Building	Monitoring, observation Awareness/assessment at state/ district/ community levels	Scientific assessment, measurement, models, national research agenda	Participation in global/ regional modelling and assessments
Knowledge/ Information	Locale-specific databases, scenarios and assessment, local monitoring networks	Research networks, National databases (e.g., NATCOM), scientific and policy models, national scenarios, technology inventory	Interface with IPCC assessments, interfacing with regional/global databases, scenarios and assessments, technology inventory database
Institutions/ Partnerships	Community initiatives, Early warning networks	Stakeholders networks, public/ private programs	UNFCCC processes, trans-boundary impact assessments
Policy/ Instruments	Locale specific adaptation plans, community-based adaptation programmes	Science-policy linkage, economic instruments (e.g., insurance, R&D funds), integration with national development/ planning process	Adaptation funds, trans-boundary regulations
Technology	Locale-specific technology adaptation	Targeted R&D, technology transfer protocols, demonstration/ pilot projects	Scientific exchange, technology transfer

predictability of weather and climate, climate change and related socioeconomic impacts, severe weather systems, middle and upper atmosphere, boundary layer and land surface processes, observation system, data archive and dissemination.

The main thrust of research in the atmospheric sciences in India is to improve the capabilities of the existing GCMs and paleao-climatological models, to simulate the past, present and future of the Asian summer monsoon under the projected biogeophysiological changes. The parameterization of sub-grid scale physical processes, including convection and land surface processes to improve the skill of models and inclusion of orography, are another thrust area. Improving the model resolution for better understanding of the monsoon is also considered as the main objective in modeling research. Other objectives are to resolve several important monsoon phases, like active and break phases, interannual variability, monsoon trough, intertropical convergence, southern hemispheric equatorial trough, easterly jet and low level jet. The interaction between the tropics and extra tropics in the monsoon region is yet to be understood, which include the role of blocking, shifts of the westerly jet and other major anomalies in the circulations of both the hemispheres. The development of physical and mathematical models of energy and mass exchange in the boundary layer of agro ecosystems and other land surface processes are also projected for the near future.

A detailed analysis of the ENSO-Monsoon relationship using Tropical-Ocean-Global-Atmosphere (TOGA) and other support from the World Climate Research Program (WCRP) is projected. Understanding the synoptic scale and mesoscale phenomena in the monsoon region using satellite cloud imagery/ Ocean-Land-Remote sensing data, radar and other conventional data, etc., is proposed. Kinematics and the dynamical study of different phases, such as onset, progression, withdrawal, break and active phases, is also considered as a thrust area. The interrelationship between the monsoon and other global circulations is to be explored using a statistical approach. A detailed study of the winter monsoon in India, which is the least studied part in Indian meteorology, is proposed as an important task to enhance our knowledge base and to improve the winter agriculture system.

Instrumental capabilities are to be improved by developing various ground-based remote-sensing systems, such as lidars, sodars, spectrometers, photometers and radiometers. These are supposed to enhance the capability of studying minor species and trace gases, including aerosols, ozone, CO_2 etc. The role of CO_2 and other such constituents in the evolution of atmospheric processes leading to the climate of the given region is to be studied for understanding the atmosphere-biosphere reactions.

Extreme events

Under the theme of extreme events, studies on the pre-monsoon thunderstorm activities in the north-eastern region of India, intense vortices within the monsoon system, such as lows, depressions, mid tropospheric cyclones and offshore vortices are important.

To lower the impact of loss due to cyclonic activities, Doppler radars are being installed along the Indian coast with the use of multi-sensor instrumented aircraft flights. Further, three-dimensional models are also being developed for the simulation and prediction of cyclones. Support is being taken from physical factors or synoptic features for studying the cyclones favourable for the development and movement of cyclones over the Indian seas, with particular interest like re-curvature and looping, formation and maintenance of the cyclone eye. Associated phenomenon, such as storm surges, are also being modelled.

Agriculture sector research

The future pathway for agriculture research includes: inventorization, characterization and monitoring of natural resources using modern tools and techniques. The development of sustainable land-use plans for each agro-ecological sub-region in the country is underway. Another agenda is to develop a system, which regulated the fertilizers usage by increasing the fertilizer-use efficiency by 8-10 per cent from the current level and its integrated use with organics and by enhancing the contribution of organics including bio-fertilizers. The management and monitoring of soils for sustainability, on-farm irrigation water management to enhance water-use efficiency, refinement of technology for economical utilization of poor and marginal quality water for agriculture, development of location-specific model watersheds in various agro-ecological zones of the rain-fed areas to enhance the productivity, are decided for the future.

Weather-based expert systems for enhanced prediction and improvement in agriculture meteorology advisory services are planned for the near future. Increasing the overall cropping intensity with an emphasis on energy efficiency and alternate agriculture, especially with low water requiring crops is proposed to be investigated. The Development of agro-forestry systems to enhance tree cover in agricultural lands to support the supply of fodder, fuel, industrial wood and small timber requirements on a sustainable basis, monitoring of climate change and mitigation of its adverse effects on agricultural production systems, is also planned.

Space sciences

The ISRO has initiated the development of many future satellites with particular emphasis on meteorological and oceanographic objectives (Table 7.4). In the next five years, it has a mandate to launch satellites with advanced payloads.

Sustenance and enhancement of established capacities

Capacity building, networking and resource commitment form the core of institutionalizing Indian climate change research initiatives. This involves a shared vision for policy relevant climate change research, scientific knowledge and institutional capacity strengthening (enhanced instrumentation, modelling tools, data synthesis and data management), technical skill enhancements of climate change researchers, inter-agency collaboration and networking improvement, and medium- to long-term resource commitment.

Several anchors have to be developed for the sustenance and enhancement of established capacities in India, based on policy needs and disciplines. Policy research includes diverse needs such as international climate change negotiation-related research, contribution to the IPCC process, sub-regional sectoral and integrated impact assessment, adaptation/response strategy formulation, mechanisms for mitigation and adaptation project selection and financing, and climate-friendly technology identification and diffusion in multiple sectors.

Sporadic research efforts are continuing in India since the last decade, such as the Asia Least cost Greenhouse Gas Abatement Strategy (ALGAS) initiative; independent climate change-related research initiatives by government ministries such as the MoEF, Ministry of Water Resources, Ministry of Health and Family Welfare, MoA and MST among others; and the National Communication project; apart from a few initiatives at the individual expert and institution level. Many Indian scientists and researchers have contributed and continue contributing significantly to the IPCC process. India's Initial National Communication project has, for the first time, brought these together in a formal network to cover diverse research areas such as preliminary sub-regional sectoral impact assessments, GHG emission coefficient development for a few key source categories, and institutional networking.

Table 7.4: Future directions (Meteorological and Oceanographic Satellites).

Name	To be launched during	Usage
CARTOSAT-2	2004-2005	Remote-sensing satellite
INSAT 3 series	2004-2005	Meteorology, telecommunications, extension programmes
RISAT-1	2005-2006	Remote-sensing satellite
OCEANSAT-2	2006-2007	Remote-sensing satellite
ASTROSAT	2005-2006	Astrophysics, environment, meteorology
KALPANA 2	2005-2006	Meteorology, environment
MEGHA-TROPIQUES	2006-2007	Meteorology, oceanography, environment

However, the procedures, methodologies, and data requirements for GHG inventory preparation are not known to most of the institutions generating activity data in various sectors. On the other hand, a few research teams in the country have the latest international expertize in preparing GHG inventories. The NATCOM project had attempted to network the two. However, the capacity-building initiatives have to be continued, widened and strengthened. The existing capacity gaps have to be identified, prioritized and then strengthened gradually. The focus has to be to institutionalize the process. Climate change research has to catch the attention and imagination of the younger Indian research community, especially in the universities and premier academic institutions, and then to keep these researchers engaged in their pursuit. There have to be sustained capacity-building efforts for a reasonable time, so that the process then becomes self-sustaining and institutionalized. Timely and sustained international funding is critical to realize this effort.

Initial institutional networks have been established and are operational under the NATCOM project. There are 19 institutions involved with GHG inventory estimation, while 17 research teams have contributed to measurement of emission coefficients in various sectors. Over 40 institutions contributed to the research initiatives on climate change vulnerability assessment and adaptation, and steps to implement the Convention (refer Annexures). These efforts have to be sustained. However, there are many more institutions in India that have individual researchers working on climate change-related aspects. Industrial associations and the private sector have also to be brought in for activity data reporting, along with government ministries and departments for consistent reporting formats. Private accredited laboratories have to be brought in to strengthen the government institutions-based GHG emission coefficient measurement activities. There are therefore, many potential partners and future centres of climate change research. Thus, it is necessary to broaden the existing networks to include all these research initiatives. This is important for creating a critical mass of researchers that would sustain climate change research in India. Networking mechanisms, particularly like data and information sharing, will require to be established and institutionalized. This would avoid duplication of effort, especially in data collection, and ensure effective resource utilization.

The networking efforts may have to be simultaneously extended to interface the research community with industry and policy-makers. Industry would benefit from the latest scientific research and GHG accounting practices. On the other hand, industry concerns and capabilities would also be reflected in research.

CLIMATE CHANGE PROJECTS

Improvements for future national communications

India would like to immediately launch the activities for preparing the Second National Communication, reflecting its commitment to the UNFCCC. India seeks further funding from the GEF for this purpose. Some of the proposed projects are indicated in Table 7.5. These include projects on improving inventory estimation, vulnerability assessment and adaptation research, and capacity building. However, this is only an indicative and not an exhaustive list.

Thematic project proposals

Some thematic potential project concepts that are over and above the specific projects presented in earlier sections are presented. These include projects for assessment of vulnerability of various socioeconomic sectors and natural ecosystems to climate change, enhancing adaptation to climate change impacts, GHG emission abatement projects, and capacity-building initiatives (Table 7.6). These however, are indicative and not an exhaustive listing of concepts. New understanding, knowledge development, resources and technology transfers will enhance India's capacity to augment this list in subsequent national communications. India needs financial assistance to convert these project concepts into specific projects for funding.

It is envisaged that activities to enable continuous reporting to the UNFCCC will involve more detailed development of local emission factors, thus reducing uncertainties in inventory estimates, focus on methodological issues, help develop regular monitoring networks, maintain and enhance national capacity through establishment

Table 7.5: Project proposals for improvements of future National Communications.

S.No	Type/ Sector	Title	Description
A	National Communication	Preparation of Second National Communication proposal document	The project will assist India in preparing a detailed proposal for 'Enabling Activities for the preparation of India's Second National Communication to the UNFCCC'
B	National Communication	Enabling activities for the preparation of India's Second National Communication to the UNFCCC	The project will assist India in undertaking the enabling activities to prepare the Second National Communication to the UNFCCC and to build capacity to fulfil its commitments to the Convention on a continuing basis.
Activity data for GHG inventory			
1	All sectors	Data format preparation for GHG inventory reporting	Presently the data being reported by the various ministries and departments at resources and sectors level shows some mismatch and the consistency cannot be easily verified. It is imperative that the available data formats be reorganized for reporting data at intra and inter ministerial levels in appropriate GHG inventory reporting formats.
2	Energy	Strengthen the activity data for GHG emission estimates from India's transport sector	Analysis of the current vehicle types and their distribution in various cities of the country and fuel use. The railways, aviation and the waterways sectors will also be covered.
3	Energy	GHG emission measurements and activity data assessment for biomass used for energy purpose	GHG emission measurements and activity data assessment for biomass used for energy purpose
4	Energy and Industrial processes	GHG inventory estimation	Data collection and GHG inventory estimation to climb the tier ladder to 2/3 tiers from the current Tier 1 for the various sub-sectors
5	Agriculture	Inventory Estimation	Evaluation of sources and sinks of GHG related to agricultural activities at disaggregated level, including data collection and validation of age-wise livestock, water regime-wise rice paddy cultivation, sub-regional crop production, sub-regional synthetic fertilizer use.
6	LULUCF	Land-use pattern assessment for India for GHG inventory estimation	Periodically monitoring and estimating the area under different forest types as well as to prepare a land-use change matrix, describing the extent of land-use change from one category to another, preferably at $1/2^0 \times 1/2^0$
7	LULUCF	Assessment of wood consumption in India for GHG inventory estimation	Estimating the fuelwood and commercial roundwood consumption, dung cake production and consumption, and agriculture crop residue consumption in India
8	LULUCF	Assessment of carbon pools in India for GHG inventory estimation	Estimating different terrestrial carbon pools, namely vegetation biomass, soil and litter carbon stocks under various land use categories and assess changes in C-pools
9	Waste	Activity data improvement for the waste sector.	Data collection and GHG inventory estimation to climb the tier ladder to 2/3 tiers from the current Tier 1 for the various sub-sectors
B.2 Uncertainty reduction in inventory estimation			
10	Energy	Development of CO_2 emission factors, linking coal beds with power plants, and impacts on their immediate environment, dispersion and transportation of emitted pollutants	(a) Power sector is one of the major contributors to the Indian CO_2 emissions. This project envisages GHG emission measurements from 40 power plants (coal and gas based). (b) Evaluation of the changing sectors of coal use,including small-scale sectors. Investigation of characteristics of coal in the country, linking them to the various coalfields. Comparative evaluation of the reliability of emission measurements by direct measurement, traditional mass balance approach and the Continuous Monitoring System. (c) Carry out dispersal modelling and ascertain the levels of emissions in and around the plants. Explore the sequestration potential of planned forest cover around the plants.
11	Energy	Development of mass emission measurement system for GHG from the automotive vehicles.	This will involve development and integration of techniques and systems for measurement of GHGs (CO_2 CH_4 N_2O) along with direct toxic emissions (CO, HC, NO_X and PM) for conventional and

S.No	Type/ Sector	Title	Description
			alternative fuels. Measurements and data generation for emission factors in gm/km of about 60 vehicle technologies and vintage combinations. Procurement and commissioning of measurement and sampling systems for GHGs.
12	Energy and industrial process	GHG emission measurement from large point sources—steel plants and cement plants	Due to high requirement of coking coal for steel production, the steel sector has a very high emissions per unit of production and contributes substantially to Indian CO_2 emissions. Similarly cement production contributes significantly to energy and process based CO_2 emissions. This project envisages GHG emission measurements from 10 steel plants and 30 cement plants. The process-based emissions will be distinguished and will be measured separately.
13	Energy	GHG emission measurement from large point sources—Petroleum Refineries	GHG emission measurements from five petroleum refineries.
14	Energy	Methane emission measure-ments from the coal mines	Cover a 100 coal mines, including opencast mining for methane emission coefficient measurements.
15	Energy	Methane emission measurement from oil and natural gas venting, flaring and transport	Cover all the major oil exploration sites in India
16	Energy	GHG emission measurement from informal/partially informal energy intensive sectors	GHG emission measurements from fully/partially informal energy-intensive sectors like brick manufacturing, sugar and ceramics etc. About 10 sectors are proposed to be covered here. The major ones being brick (sample about a 100 kilns), sugar (sample about 50 units), soda ash (sample about five units), textile (sample about 20 units), ceramics (sample about 30 units), and chemical and dyes (sample about 30 units).
17	Industrial Processes	Reduction of uncertainties in GHG emissions factor in lime and cement sectors in India	This project will help to reduce the uncertainties in CO_2 emission coefficients derived for the first phase of NATCOM. The work programme will entail systematic collection of CO_2 fluxes, samples of raw materials, intermediate and final products for analysis. About 50 cement plants representing prevalent technologies for producing cement in India will be covered.
18	Industrial Processes	GHG emission coefficient measurements from industrial processes	GHG emission coefficient measurements from industrial processes like nitric acid production, aluminium production, soda ash use and pulp and paper production.
19	Agriculture	Nitrous oxide emission from selected agricultural fields of rice and paddy	Irrigated rice and dry land farming are major sources of CH_4 and N_2O in selected agroecological zones consisting of irrigated as well as dry land farming. The project will measure CH_4 and N_2O emission coefficients from these.
20	Agriculture	(a) Measurement of CH_4 and N_2O emission coefficients for rice cultivation (b) Development of emission coefficient of non-CO_2 gas emissions from major agriculture crop residue	This will involve setting up a network of stations for continuous and more refined measurement of these emissions for the entire season of rice growth and year, assessment of fertilizer used, types of cultivars planted, soil carbon etc., to ascertain the dependence of CH_4 and N_2O emissions on these parameters. Also individual measurements of changes in CH_4 emission under increased CO_2 environment using the FACE facility will be carried out.
21	Agriculture	Measurement of CH_4 and N_2O emission coefficient from enteric fermentation in animals and manure management.	This will involve establishment of CH_4 emission coefficients from different types of animal categories in India, with the focus on the major emitters and N_2O emission coefficients measured from different types of manure management.
22	Agriculture	Measurement of N_2O emission coefficients from major soil types in India	This will involve establishment of network of stations for taking year long measurements of N_2O for representative soil types in India. To assess the organic carbon contents of Indian agricultural soils at
23	Agriculture	Soil carbon content assessment	$1/2^0$ x $1/2^0$ grid. (a) This will involve the establishment of towers inside and outside
24	LULUCF	CO_2 emission and uptake measurements in specific forest types/areas to ascertain their net sink capacity	forests fitted with on-line CO_2 measuring equipments and weather parameters, including temperature, humidity and wind direction. (b) Determination of the rate of photosynthesis, transpiration, leaf area and canopy cover of different native and planted species vis-à-vis reduction in GHGs especially, CO_2.

S.No	Type/ Sector	Title	Description
25	LULUCF	Soil carbon measurements, Soil carbon cycle modelling remote sensing and generation of GIS based-mapping of land use for Indian forest	(a) Setting up of a network of stations for measuring soil carbon for different soil types in India. The measurements will be carried out according to the IPCC specification of soil depths. (b) Carbon cycle modelling will be developed. (c) To get a perspective of the land use and forestry of the Indo-Gangetic region of India, GIS-based maps will be developed by decoding remote-sensed data for use in emission inventory from this source in the future.
26	LULUCF	Uncertainty Reduction	Generating Emission Factor/Sequestration Factors for GHG inventory in the LULUCF sector of India.
27	Waste	Measurement of emission coefficients from domestic and commercial waste water	(a) Measurement of CH_4 emission coefficient from domestic waste water with distinctive composition (b) Measurement of CH_4 emission coefficients from representative major affluent producing industries.
28	Waste	Methane emission from selected landfill sites	Methane measurements will be carried out in identified major landfill sites in cities with population greater than one million. The likely cities to be selected for this study will be: Mumbai, Delhi, Chennai, Kolkata, Bangalore, Hyderabad and Ahmedabad in India, where systematic collection and dumping of solid waste takes place.
29	All	Undertake climate change related environmental studies (background measurements)	Continuous in-situ monitoring of concentrations of GHGs (CO_2, N_2O and CH_4) from base line stations at Kodaikanal and Shillong using Gas Chromatographic Analysers. Regional grab sampling programme for GHGs using stainless steel sampling flasks and Gas Chromatographic analysis from a central laboratory.
B.3 Vulnerability assessment and adaptationn			
30	Climate Change Modelling	Generation of high resolution regional climate change scenarios and investigating its impact on the Indian monsoon and on extreme climate events	(a) This will involve detailed diagnostic analysis of climate model control runs to assess the skill in simulation of present day climate and its variability over India; (b) Analysis of perturbed simulations with IS92a/SRES emission scenarios to quantify the climate change pattern over India with reasonable high resolution during the 21st century; (c) Application of regionalization techniques to improve the assessment of climate change on regional scale; (d) Study of the sensitivity of monsoon climate to natural/ anthropogenic perturbations by model output diagnostics and numerical experiments; (e) Perform climate change experiments with global AOGCMs as well as regional climate models, with special emphasis on the development of realistic scenarios for the Indian region; (f) Examination of the nature of possible changes in the frequency and intensity of severe weather and climate events (e.g., droughts/ floods, cyclonic storms). (g) Interaction with various impact assessment groups and design specific climate change data products for use in their models through workshops and meetings; (h) Warehouse for storage of all validated and downscaled AOGCM data products for South Asia, designed for regional climate change impact assessment, high-resolution scenario data for different administrative units of India (e.g., states) and provide regular up gradation to keep pace with developments in the area.
31	Indian Emission Scenarios	Generation of future GHG emission scenarios for India	Articulation of alternate development pathways for India and quantification of key driving forces. These alternate scenarios will be congruent to IPCC-SRES scenarios and Indian climate change scenarios.
32	Various relevant sectors	Development of vulnerability and adaptation scenarios for India	Develop sub-regional vulnerability and adaptation scenarios for India which integrate the cross linkages between different sectors of the economy. These scenarios will be congruent to the Indian climate change and emission scenarios.
33	Agriculture	Assessment of vulnerability of the Indian agriculture sector	(a) Studying the impacts of enhanced level of CO_2 using Mid-FACE

S.No	Type/ Sector	Title	Description
		due to impacts of climate change and formulation of adaptation strategies.	facility in the country on grain yield of cereals important to the economy (rice and wheat). The cereals under each category should be of different types of cultivars. (b) Incorporating these results into modelling (c) Case study to understand the impacts of climate change on important crops in the country using the modelling approach and formulating a matrix of alternate cultivar/cropping pattern/farming
34	Water Resources	To study the impact of climate change on the water resources and to develop adaptation strategies	practices etc., to adapt to climate change. (a) A national assessment of water resources taking into account the climate change. (b) To identify future water scarce zones in the country. (c) To undertake case studies in some of the anticipated water scarce zones in the country and devise adaptation strategies for availing
35	Water Resources	Reducing uncertainties in assessing climate change variability and extreme events such as droughts and floods in India	water. Enhancing the temporal and spatial resolutions of GCM/ RCMs models to be more specific to India and using the precipitation and temperature series thus generated, as input to hydrologic models for forecasting droughts/ floods' variability and extremes in: select water stressed river basins (Sabarmati in Gujarat and Palar in Tamil Nadu),
36	LULUCF	To study the impact of climate change on forestry and formulate adaptation strategies	and select flood prone basins—Ganges and Meghna. Develop current (and past) climate and vegetation type linkages, correlation's and geographic maps of distribution. Evaluate, adapt and develop vegetation response models suitable for the complex, diverse vegetation types in India. Assess the vulnerability of different ecosystems to different scenarios of climate change. Assess the impacts of different climate change scenarios on vegetation ecosystems in terms of shifts in boundary, changes in area, biodiversity, regeneration and growth rates, and carbon sink capacity. Evaluate different adaptation options and implementation barriers to reduce adverse impacts of climate change. Develop policy, institutional and financial measures to implement adaptation
37	Natural Ecosystems	To study the impacts of climate change on natural ecosystems, such as the Sunderbans	measures. This will involve study and modelling of impacts of climate change including sea-level rise on the dominant forest species in Sundarbans. Modelling the impacts of sea-level rise on appearance
38	Human Health	To study the impacts of climate change on human health Impacts of climate change and extreme events on coastal zones	and disappearance of islands in the Sundarban area. This will involve identification of areas where malaria and diseases related to extreme heat or cold events will be prevalent in the future climate scenarios. Identification of communities most susceptible to climate change. Undertaking case studies integrating climate change and socioeconomic scenarios. Development of adaptation matrix to
39	Extreme Events and Coastal Zones	Integrated model development for assessment of impacts on energy sector	combat the impacts of climate change. (a) This study will include development of a sea-level rise scenario due to climate change along the coastline of India. Study on impacts of sea-level rise on specifically densely populated and area with important infrastructure.
40	Energy	Impacts of climate change on energy and infrastructure in the country	(b) Impacts of sea-level rise on fisheries. Developing software modules for impact assessment of climate change on energy sector and 'soft linking' the same with models of
41	Energy and Infrastructure		inventory estimation to obtain an integrated view. (a) This study will involve specific case studies to evaluate the impacts of climate change on the energy availability and urban infrastructure in India. (b) Evaluation of adaptation strategies including insurance to combat
42	Energy and Infrastructure	Development of urban policy response for integrating climate change and sustainable development	the impacts. This will involve identification of issues in urban areas relevant to climate change and a development of methodology for linking them to sustainable development.

S.No	Type/ Sector	Title	Description
B.4 Capacity building/ enhancement			
43	Inventory Estimation	To establish a GHG reference laboratory for generating and disseminating certified reference materials	(a) This will involve the preparation and dissemination of gas-CRMs of CO_2, CH_4, and N_2O. Calibration of Gas Chromatographs (GCs) used for baseline monitoring for above gases. (b) Preparation of uncertainty budget for baseline monitoring for above gases for homogenization of uncertainty of measurements. Validation of test methods and organization of proficiency tests
44	Inventory Estimation	Nodal centre for synthesis and coordination of uncertainty reduction in GHG emissions	for measurement of the above gases. This centre will essentially validate, synthesize and ensure the application of good practices for uncertainty management and quality assurance and quality control. Periodic training will be conducted to update researchers on the latest good practice guidance techniques for undertaking measurements and also train personnel for undertaking measurements in various sectors. Following the guidance specified by the IPCC Good practices report, this agency
45	Vulnerability Assessment and Adaptation	Integrated impact assessment for India, including long-term emission scenarios, GHG abatement policies and adaptation measures.	will act as a third party for implementing the QA measures. Develop an integral impact assessment modelling framework for India using sectoral models, consistent scenarios and databases. It is proposed to deploy modular integration, i.e., integrating modules consisting of individual sectoral models, run using similar climate, emission and socioeconomic scenarios. The basic thrust will be on
46	Energy	Setting up of an Indian energy systems model for medium- and long-term energy and environmental policy	generating common and finely gridded databases for use in models. Economy-energy-environment modelling using Indian emission scenarios and shared databases developed under other projects. Major outputs will include the projection of alternate GHG emission pathways, energy intensities, technology and fuel mix, and energy
47	All sectors	Organizational and institutional issues for climate change	sector investment requirements for India in medium to long term. Creating awareness at all levels (grassroot to policy) on climate change, vulnerability and adaptation issues for industry and infrastructure, energy, agriculture, LULUCF sectors, through sectoral workshops in various (vulnerable) regions of the country;
48	All Sectors	Educating and informing the corporate sector about the emission abatement technologies and projects.	dissemination; publication, etc. (a)Create awareness about climate change in the business sector, especially on impacts on industry, cleaner production, CDM, etc. b)Role of insurance as a tool of adaptation for long-life assets.
49	LULUCF	Modelling efforts	Develop technical and institutional capacity for modelling, monitoring and verification of C-stock changes in LULUCF projects involving: developing models for predicting changes in stocks of different pools in different types of forestry projects; build capacities of institutions to undertake these activities; assisting project developers and project promoters; and, developing information packages.

of nodal centres for climate change research, impact assessment and adaptation-related activities, and increase public awareness through information dissemination and education. The following thematic activity areas may be covered to strengthen the scientific capacity in India to respond to climate change challenges and lay the foundation for further national communications and implementation of the Convention.

- Establishment of systematic observation networks for monitoring emissions of GHGs, other trace gases and pollutants
- Improvement in GHG emission estimates in key sectors for improved future national communication by regular monitoring and measurement of emission coefficients in the energy, transport, industry, agriculture, forestry and waste sectors.
- Development of high-resolution regional climate scenarios for India.
- Development of socioeconomic scenarios for India
- Institutional and human capacity building for undertaking research on Integrated Impact

Table 7.6: Research and demonstration project proposals for adaptation, vulnerability assessment and abatement.

S.No	Sector	Title	Description
A	**Adaptation**		
1	Agriculture	Crop insurance and climate change	Research to understand performance of various insurance models to develop comprehensive crop insurance packages for Indian farmers.
2	LULUCF	Vegetation modelling	Develop, validate and disseminate dynamic vegetation models for assessing impact of climate change on the forest ecosystem at the regional level, including: the evaluation of existing dynamic vegetation models; adaptation/ modification/ development of dynamic vegetation models for application at regional scales; validation for current climate and vegetation; and, dissemination of information package on the dynamic vegetation model**.**
3	LULUCF	Ecosystem modelling	Long-term monitoring of vegetation response in Himalayan Ecosystem/Western Ghats with wide altitudinal gradient to changing climate, along the latitudinal and altitudinal gradient, specifically including: monitoring climate changes and monitor vegetation changes; establishing linkages between climate change variables and forest vegetation characteristics.
4	LULUCF	Adaptation policies for forest ecosystems	To assess the impact of forest policies, programmes and silvicultural practices, to enhance resilience or reduce the vulnerability of Himalayan Ecosystems/ Western Ghats with wide altitudinal gradient forest ecosystem to projected climate change. Specifically it will include: review of forest policies, programmes and silvicultural practices in selected regions; suggesting policies, programmes and silvicultural practices to reduce vulnerability of forest ecosystems; assessing the implications of biodiversity, silvicultural practices and dominant species to determine the vulnerability of forest ecosystems.
5	LULUCF	Assisting adaptation for vulnerable plant species	Anticipatory planting of vulnerable plant species in Himalayan Ecosystems/ Western Ghats to adapt to projected climate change involving: identifying vulnerable species which are likely to migrate; planting along altitudinal gradient; monitoring performance of species; and making recommendations on anticipatory planting practices.
6	Coastal Zones	Integrated adaptation policies for coastal zones	Identifying points of integrating the adaptation policy, having elements of both coastal zone management and sustainable development, into national, regional and local developmental planning and policies. Specifically, it will include: review of other policies—disaster abatement plans, land-use plans, watershed resource plans; understanding 'local livelihood stresses', induced due to environmental factors such as groundwater degradation due to sea water intrusion, coastal flooding and erosion; understanding and documenting the local traditional knowledge systems used in combating these non-climatic stresses and climate change induced enhanced variability and extremes in flooding.
7	Agriculture	Small and marginal farmers	Develop suitable adaptation policy and implementation of a few pilot schemes to enhance the adaptive capacities of small and marginal farmers in India.
8	Water Resources	Arid and semi-arid regions	Developing check-dams and water harvesting demonstration projects in each of the arid and semi-arid districts in India.
9	Agriculture, Forestry and Water Resources	Conventional adaptation practices	Develop a compendium of rational indigenous and traditional practices on adaptation in selected sectors like agriculture, forestry, water resources (floods and droughts) in various agro-ecological regions of India.
10	Industry	Research on innovations	Research on adaptation innovations in Indian industry for adaptation to climate change impacts.
11	Agriculture	Agronomic management	To evaluate alternate agronomic management options to sustain the agricultural production in relation to changed soil moisture availability in flood and drought prone regions.
12	All	Integrated impact assessment modeling for India	Developing integrated assessment models for India to assess the impacts of climate change and corresponding adaptation requirement, in addition to understanding possible abatement and adaptation measures, in various sectors —water resources, agriculture, terrestrial and marine ecosystems, human health, human settlements, energy, and industry.
B	**Vulnerability**		
13	All	Extreme events and identification of	Impact assessment to address a range of possible increase in temperature scenarios in floods, cyclones and droughts prone regions, as these different geographical

S.No	Sector	Title	Description
		vulnerable regions in India	regions are expected to experience variability in temperature changes due to climate change.
14	All	Economic scenarios and vulnerability to Climate Change	Conducting scenario based studies for various possibilities of extent of climate change impacts, e.g., for a range of increase in temperatures, rise in sea water level, deforestation, economic growth and emissions, and abatement efforts etc
15	Infrastructure, Industry	Climate change impact on coastal infrastructure and Industries	Coastal infrastructure is most vulnerable to the sea-level rise and extreme events. India has many industrial complexes close to the coastal areas. The infrastructure such as roads, railway lines, and ports will be adversely affected by the changing rainfall pattern and extreme events.
16	Energy	Impact of Climate Change on energy demand and resultant change in emission pattern	Increase in temperature and changing climate is likely to affect the energy demand. Almost all the sectors will experience change in the demand based on the location. The increased demand for energy will also affect the resultant emissions, as most of the increased demand will be fulfilled by the power sector, which depends primarily on coal.
17	Agriculture	Soil and crop productivity	Evaluating the impact of climate change and its variability on soil and crops' productivity (five years).
18	Water	Impacts of climate change on water resources on transportation sector of agriculture goods	Mapping the existing inter-state flow volume of agriculture goods and assessing impact of 'drought' conditions on reduction in transportation and assessing opportunities for adapting to shortfalls in agriculture production relative to food security.
19	Agriculture	Developing genetic modified species	Will involve developing species and conducting trials of the same, and disseminating the findings through bio-technological advances for improving crop yields in drought prone states
20	Water resources	Assessing the effect of global warming on major Indian rivers and aquifers	This study will assess aquifers and their behaviour in Indian peninsula vis-à-vis their exploitation for water and hence GHG emissions.
21	Water resources	Impact of climate change on water availability in Himalayan glaciers and rivers	Himalayan glaciers and rivers have an important role in the Indian water supply system. Temperature increase due to climate change may bring about changes in the Himalayan ecosystem, which will alter the water availability for India in the short, medium and long term.
22	Water resources	Developing hot-spot (extreme scarcity) areas in water resources sector and developing micro-level (household and community level) assessments of vulnerability and impacts of droughts	(a) This will involve preparing overlays of maps—such as drought hazard maps, groundwater development and degradation maps, surface water development, road network, state domestic product, state human development indices, and superimposing the same to assess hot-spots for detail assessment of micro level vulnerability assessment (b) Based on the identification of hot-spot states as above, conducting field surveys in a 100 randomly proportionate stratified sampled villages in each state for a total of 400 villages.
23	Water resources	Mapping vulnerable population due to climate change impacts on water resources	Mapping national level temporal (at five year intervals) and spatial (at state level) distribution of vulnerable population at risk at state level due to climate change impacts on water resources. This will involve mapping the current demographic trends in urban and rural population growths, overlaying the same with state developmental plans on infrastructure in water supply sector and water sector reforms parameters.
24	Industry and infrastructure	Assessment of Impacts on industry and infrastructure	Assessing impacts on industry and infrastructure through preparation of a catalogue of historic extreme events, assessing the damages and providing the loss estimates in coastal and inland areas, showing the spatial distribution; developing detail GIS map covers with topographic, vegetation and geological details showing the major industries and infrastructure systems and their components; and assessing sensitivities of different components with respect to various climate parameters.
25	Agriculture	Gridded database generation	To characterize the extent of rainfall variability, surface and ground water availability in various agro-ecological regions of the country at $1/2^0$ x $1/2^0$ grid (or finer).
26	Agriculture, Forestry and Water Resources (livelihoods)	Asset vulnerability assessment	Research to understand vulnerability by assessing type and extent of various livelihood assets—social, physical, financial, institutional and natural—of communities from various potential impact geographical regions.

S.No	Sector	Title	Description
27	Coastal zones	Vulnerability assessment at coastal village level	Assessing vulnerabilities of communities from a 100 villages along the coast to climate change impacts by use of sustainable livelihood framework. Analyzing social dynamics and institutional landscape to identify points of leverage for short-term and long-term adaptation interventions.
28	Health	Vulnerability assessment of areas where malaria has been predicted to shift in the climate change	Assessment of vulnerability of communities to be affected by malaria in areas above 1800 m and in coastal areas will be the focus of this study. The accessibility to health facilities, and assessment of current adaptation practices and the policies of the government will be reviewed to understand the adaptation needs of the afflicted communities in the climate change regime.
29	Health	Assessing vulnerability of communities exposed to extreme heat	Extremely high temperatures have been recorded in recent times in northern , central and south eastern parts of the country, which have caused mortality. A study will be carried out to identify areas which will experience recurrent intense heat due to climate change and assessment will be made of adaptation needs of communities in the climate change regime. For this, the current adaptation practices including the government policies will be analyzed.
C	**Abatement/ Capacity development**		
30	Energy	To study the level of non-coking coal beneficiation and its impact on efficiency improvement/ abatement of GHG emission in thermal power stations.	This will involve a detailed study of non-coking coals for identification of quality parameters including combustion behaviour. Estimation of the impact of coal quality on the boiler efficiency. Quantitative assessment of the effects of the variations of fuel quality on the performance of the critical sub-processes involved in power generation and GHG emission.
31	Energy	Validation of the Multi Stage Hydrogenation (MSH) technology for converting coal to oil	(a) The aim is to confirm the results of the batch reactor studies. (b) Establish viability of the process through generation of technical data required upscaling the process to higher scale. (c) Research for increasing the present yield of distillates from 60% higher yields between 85% - 90 %; commercial viability of this project.
32	Energy	Utilization of GHG (CO_2 and Methane) for production of fuels and chemicals.	This will involve conversion of CH_4 and CO_2, producing syngas with low H_2 / CO ratio, (nearer to one) which is highly desirable in gas to liquid fuels conversion technology using iron-based catalysts. Conversion of methane gas by development of solid acid catalysts based on heteropoly acids and other catalysts to value added chemicals like methanol, formaldehyde and ethylene.
33	Energy	Abatement of GHG via *in situ* infusion of fly ash with CO_2 in thermal power plant: upscaling of the process vis- a- vis associated carbon sequestration and adoption.	(a) This will involve characterization of fly ash samples from 2-3 representative thermal power plants of the country in respect of various physico-chemical parameters including minerals and trace and heavy metals content. Carry out experiments, under laboratory conditions, on CO_2 infusion of these fly ashes at varying pressure. (b) Assessment of extent of infusion of fly ash and consumption of CO_2 therein. Experiments on leaching characteristics of fly ashes (treated and untreated) with CO_2 infusion following shake and column tests.
34	Energy	Minimization of CO_2 and other polluting gaseous levels by suitably developing soft coke technology as the source of rural/ semi-urban domestic energy	This will involve development of more energy efficient soft coke technology utilizing inferior coal. Development of suitable provisions for less emitting/arresting the GHG. Improvement of the present technology for making it more suitable for rural use. Generation of data /techno-economic as well as socioeconomic evaluation. Improvement in design/development of the fixed/movable domestic soft coke cook-stove in view of energy efficiency as well as emission of GHG
35	Energy	Cleaner electricity production through fuel cell technology	The present project will develop a 200 KW SOFC system operating at 800^0 C. The performance of this system will be evaluated with reformed natural gas fuel as well as with coal gas.
36	Energy	CO_2 Sequestration in geologic formations with enhanced coal bed Methane Recovery.	This will involve examination of the potential for CO_2 sequestration in geologic formations/un-mineable coal seams. Identification of un-mineable coal seams/ geologic formations in India suitable for CO_2 sequestration. Develop mathematical models for reservoir simulation of CO_2-CBM and a mathematical model for gas-water flow in coal beds.

S.No	Sector	Title	Description
37	Energy	Improvement in solar cell efficiency	R&D studies to improve the efficiency of solar cells to 15% at commercial level and 20% at research level. This will be built on the ongoing programme of the Ministry of Non-Conventional Energy Sources.
38	Energy	Energy Penetration of energy efficient technologies	Demonstration projects for increased penetration of efficient technologies (supply and demand management based) such as, heat rate reduction, electric arc furnaces, energy efficient processes, efficient lighting and agriculture pump-sets, in order to enhance scale and acceptance of efficiency interventions for GHG emission abatement.
39	Energy/ petroleum	Energy/petroleum geological storage of CO_2 in exploration/ recovery of petroleum gas.	This will involve injection of CO_2 in the petrioleum wells for recovery of petroleum gas and other products.
40	Energy	Energy Removal/ absorption of CO_2 through absorptive media	This will involve the identification, characterization of different absorptive media for CO_2 removal and its absorption in thermal power plants.
41	Energy	Energy CO_2 decomposition through plasma technology	This will involve the use of an arc discharge device where CO_2 will be dissociated with ionized to give rise to carbon and oxygen ions. A directionally aligned magnetic field can be used to separate the carbon and oxygen ions. The carbon ions so deflected with the help of magnetic field can be separately collected.
42	Energy and Agriculture	Energy and Agriculture recovery of methane from landfills and paddy fields	This will involve the study of methane efflux in different seasons at various sites. The components of the measurements will include investigation on CH_4 production potential of different methanogenic bacteria under different conditions, the process of augmentation of CH_4 formation through biological and non-biological means, the suppression of CH_4 oxidation through manipulation of edaphic factors and the use of inhibitors. The study will also investigate and demonstrate the options for maximum recovery of CH_4 gas from landfills and paddy fields for heat and electricity production.
43	Industrial Processes	Ecologically-friendly and value added steel making process based on VRDR-SAF-ESR route	The proposed process attempts use hot charging of DRI into submerged arc furnace (SAF)/ Electro-slag Crucible Melting Furnace (ESCF), from which the hot liquid steel enters the electro-slag casting equipment to produce high quality alloyed steel product of near-net shapes. The process is expected to be environment friendly and techno-economically attractive even on a medium scale of operation. The process has the flexibility to treat various feed materials and produce a range of different steel products based on the local demand. Since the DRI-based route by-passes the conventional components such as coke and sinter making, the process would require much less energy and would lead to substantial reduction in emission of CO_2 to the atmosphere.
44	Industrial Processes	Non CO_2 GHG emission abatement from process industries.	Abatement demonstration projects in industries such as nitric acid, paper, adipic acid.
45	Agriculture	Cost-effective abatement strategies for the Indian agriculture sector	Developing abatement strategies for GHG reduction; socioeconomic evaluation of the abatement strategies; possible consequences of the suggested abatement options on agro-ecological system (short- and long-term consequences).
46	LULUCF	Enhancing agroforestry in India	Implementing agroforestry in dry land farms to increase the tree resources on farms, increase the economic returns and to increase C-stocks in any rain fed region/ states such as Karnataka, Andhra Pradesh, Tamil Nadu, Madhya Pradesh and Haryana. The scale of the project would be 20,000 ha, covering about 20,000 to 40,000 farms.
47	LULUCF	Energy plantation in India for GHG emission abatement	Provide biomass sustainably for generation of biomass power, substituting fossil-fuel energy in any of the states facing power shortage such as Karnataka, Tamil Nadu and Andhra Pradesh and where power generation is mainly from coal-based power plants. The activities will involve: raising mixed species energy plantations in about 6000 ha in a phased manner, using high yielding package utilities; developing and implementing sustainable biomass harvesting practices to supply feedstock to biomass power utilities; and, installing biomass power plant of 20 MW and supplying electricity to meet the decentralized power needs.

S.No	Sector	Title	Description
48	LULUCF	Carbon sink enhancement and sustainable development in villages	Developing, implementing and disseminating an integrated and participatory approach to revegetation of village ecosystems for enhancing carbon sinks, conserving biodiversity and enhancing sustained flow of benefits to the local communities in the Western Ghats region in about 10,000 ha, extending over a 100 villages.
49	LULUCF	LULUCF degraded forest regeneration	To sequester carbon by regenerating degraded *sal* forests of Orissa, West Bengal or Bihar involving: regenerating degraded *sal* forests for timber and non-timber forest products; involving local communities in protection and management of regenerating forests; and, promoting biodiversity.
50	LULUCF	Mangrove ecosystem rehabilitation	Rehabilitating about 20,000 ha degraded mangrove ecosystem in Orissa to protect the coastal lands and sequester carbon involving: identifying degraded mangrove; protecting and regenerating mangroves; monitoring the biodiversity, growth rate and C-stock changes
51	Energy, Industry and Infrastructure, and Waste	Issues in technology transfer for abatement of GHG emissions in India	Facilitating transfer of technology from developed to developing countries. through joint research and development, and adoption.
52	Industry	Fiscal instruments for emission abatement from Indian industry	Research and pilot projects.
53	Energy	Role of technology in abatement and adaptation of climate change impacts on energy sector	Conduct intensive studies for abatement and adaptation of energy efficient technology and methods and identify points of leverage in market chains and institutional regimes for demand side management measures for abatement.
54	Agriculture	Carbon sequestration in agriculture soils	Research and demonstration projects to sequester carbon in agricultural soils by adopting appropriate land use options.
55	Energy	Fuel switching	Research and demonstration projects for penetration of low and no carbon fuels in transport sector.
56	Industry	Industry energy efficiency improvement	Research and demonstration of energy efficient technologies in energy intensive SSI in India.
57	Agriculture Energy	Agriculture enteric fermentation Energy CO_2 capture and storage	Research, development and demonstration of low-methane emitting feeds Demonstration project for CO_2 capture and storage at one high concentration CO_2 stream plant in India.
58	LULUCF	Ecosystem development and conservation	Integrated and participatory approach to revegetate village ecosystems in Karnataka for carbon sink enhancement and biodiversity conservation through sustained livelihood development.
59	LULUCF	Carbon sequestration	Carbon sequestration and biodiversity conservation in the Uttaranchal hills by holistic initiatives in village agro-ecosystem.
60	LULUCF	Rehabilitate arid lands	Integrated ecosystem approach to rehabilitate degraded arid and semi-arid lands of western India for combating desertification.
61	Energy	Renewable technologies	Rural electrification using solar photovoltaic technology-based mini-grids in ecologically fragile and geographically inaccessible areas.
62	Energy	Renewable technologies	Cleaner and efficient technology interventions in small and medium scale industries in India, using biomass gasifier system.
63	Energy	Renewable technologies	Increased market penetration of solar thermal technologies for low/medium grade heating applications in India
64	Waste/Energy	Waste to energy	Efficient utilization of organic solid wastes for energy and resource recovery and GHG abatement.
65	Energy	Renewable technologies	Sustainable bagasse based cogenerated power distribution in the command Area of Shri Tatyasaheb Kore Warana Sahakari Shakkar Karkhana (STKWSSK) Ltd in Taluka Panhala, District Kolhapur, Maharashtra.
66	Energy	T&D losses	Reduction in transmission and distribution losses
67	Energy	Waste to energy	Power generation from refinery residues using IGCC technology.
68	Energy	Carbon abatement	Reduction of carbon emission by renovation and modernisation of old coal-fired thermal power plants.
69	Energy	Carbon abatement	Efficiency improvements in the Indian brick industry.
70	Energy	Carbon abatement	Demonstration of coal gasification and supply of coal gas to tunnel kilns in pottery.
71	Energy	Waste to energy	492 MW IGCC power plant, based on refinery residue-vistar

S.No	Sector	Title	Description
72	Energy	CO_2 capture and storage	Identification and carrying out geological mapping of potential areas for CO_2 capture from large point sources and subsequent storage in India like in sedimentary rocks, unmineable coal seams, depleted oil wells, etc to evaluate total CO_2 storage capacity available in the country and its long term implications.
73	Energy	Fuel Switching	Design and development of zero emissions coal fired thermal power stations wherein coal will be gasified and CO will be converted in CO_2 by shift reaction and hydrogen will be used for power generation employing fuel cell / turbine to get zero emission power.

Assessment and adaptation policy formulation for various sectors in India.

- Consolidation of indigenous efforts for climate change abatement, including energy efficiency improvement efforts in various sectors, transfer of cleaner technology, promoting the use of renewable technologies, etc.
- Clearing house for climate change related database management and processing
- Strengthening and building of human and institutional capacity in India for energy and environment sector modelling.

There is a need to form a network of stations, which will monitor the background GHG concentrations in pristine areas and also concentrations in polluted areas. For this, measurement facilities need to be set up at pristine areas such as at high altitude Hanle in Ladakh (the Himalayas), at Sundarbans in West Bengal, at Kodaikanal in Tamil Nadu, and the Andaman and Nicobar Islands in the Bay of Bengal. These stations need to run like the Global Atmospheric Watch (GAW) stations to measure the GHG concentrations continuously.

India has enormous potential for implementing climate change projects. This is primarily because the power sector in India is still predominantly coal based and the vintage technology status in the power and transport sector have considerable potential for efficiency improvements. Abatement projects are mainly in the areas of energy efficiency, renewable energy and sustainable transports. The capacity to develop bankable detailed project proposals can be enhanced in India. It is critical to ensure minimum performance standards, codes and certification for energy auditors. Energy managers in industries need training. Commercial banks also need to gradually build their own technical capacity. A project-financing approach to lending has to be promoted rather than collateral-based loan financing for energy efficiency.

Additionally, the forest sector provides large potential for the removal of carbon. Though the deforestation rate in India has reduced in the recent years, the vast degraded lands can be used for afforestation and hence for the sequestration of carbon. For example, lands in and around mines and the abandoned agricultural lands can be the initial targets for afforestation.

The Asia Least Cost Greenhouse Gas Abatement Strategy (ALGAS) study conducted by the Asian Development Bank (ADB) had identified technological improvement in Indian power plants, fuel switching in Indian power plants, using less polluting fuels in the transportation sector and the use of renewable energy technologies as the possibilities for abating GHG in the Indian energy sector. In the forestry sector, the activities are: forest conservation and expansion of sinks by reforestation of degraded forest areas and afforestation in private land. In the agriculture sector, the activities are: change in feedstock to contain methane emissions from livestock, changing paddy cultivation practices to reduce methane emission from continuously submerged paddy fields and the appropriate reduction of nitrous oxide emission from fertilizers.

Some other thematic areas of research that require support and further development, as appropriate are: international and intergovernmental programmes and networks or organizations aimed at defining, conducting, assessing and financing research, data collection and systematic observation. This may include:

- Forecasting energy requirements.
- Energy usage efficiency studies from producers

to user groups.

- Socioeconomic costs related to climate change i.e., increased vulnerability to climate change.
- Effect of climate change on marine infrastructure, business and marine ecosystem.
- Conservation studies.
- Assessment of carbon abatement potential.
- Design of the Indian economic modelling in conjugation with global economic modelling based on carbon and energy intensities, and the cost reductions from trading, including the compatibility of domestic and international mechanisms, constraints on emissions trading, transaction costs, and marginal cost estimates.
- Analyses of 'spillover' effects on non-Annex I countries.
- Technology development and diffusion for cost-effective stabilization studies.
- Studies on emission pathways.
- Studies to assess incentive needed for promotion of energy efficient technologies .
- Promotion of research on energy efficient building technologies and development of codes and standards for the sector.
- To conduct environment policy research for economic development and environmental changes

NEEDS FOR ADAPTATION TO CLIMATE CHANGE

Reduction of GHG emissions, leading to stabilization of their concentrations in the atmosphere in the long run, will neither altogether prevent climate change, sea-level rise, nor reduce their impacts in the short to medium run. Adaptation is a necessary strategy at all scales, from national to local, to complement climate change abatement efforts; thus, together they can contribute to sustainable development objectives and reduce inequities.

In addition, the development of planned adaptation strategies to address risks and utilize opportunities can complement abatement actions to reduce climate change impacts. However, adaptation would entail costs and cannot prevent all damages. There are many constraints faced by the developing countries such as India while deploying the scarce resources for adaptation measures.

Afforestation on degraded land.

Need for awareness at all levels

There is a need for enhancement of awareness at all levels on adaptation needs. The nature of adaptation needs would differ from location to location and sector to sector in an economy and even at the micro level, across different economic activities in a locality. These also need to consider the stakeholder's perspective and their difference in endowment of resources and capacity.

Need for research on formulating specific adaptation measures for various sectors

Sectoral adaptation measures would depend to a large extent on the awareness and understanding of the climate change impacts. Various sectors like water resources, agriculture, terrestrial and marine ecosystems, human health, human settlements, energy, and industry, have their unique adaptation requirements and there is a need for research to understand the extent of climate change impacts and the possible sectoral adaptation measures.

Need for inter-linkages in adaptation policy and market responses

Adaptation to climate change presents complex challenges, as well as opportunities in many sectors. Policy formulation on adaptation measures has to relate to the complex sectoral interdependence and inter-relationships in climate change impacts. This area has been scarcely researched in the Indian context and information necessary at the local level for adaptation policy planning is generally not available. This in turn also affects coordination with the market responses in adaptation. Market responses would not be forthcoming if there is no clarity in cause-effect. Further in the absence of proper information, the policies do not reflect such clarity and free riding prevails. Developed countries have experienced cases of complacency and maladaptation fostered by public insurance and relief programmes. The developing countries, which may experience adverse effects of climate change, have to deal with equity issues and development constraints in market responses. Market responses must be matched with extensive access to insurance and more widespread introduction of micro-financing schemes and development banking.

Need of resources to implement adaptation measures

The costs of adverse events have risen rapidly despite significant and increasing efforts at fortifying infrastructure and enhancing disaster preparedness in the recent decades. Part of the observed upward trend in disaster losses over the past 50 years is linked to socioeconomic factors, such as population growth and urbanization in vulnerable areas. Moreover, climate change impacts occur in the long term and for a sustained level research to enhance preparedness requires enormous resources in developing capabilities in knowledge and infrastructure.

TECHNOLOGICAL NEEDS

The Government of India has been promoting low CO_2 emission technologies for sustainable development through programmes such as the Integrated Renewable Energy Programme. India has one of the largest programmes for promoting renewable energy in the world, covering all major renewable energy technologies, such as, biogas, biomass, solar energy, wind energy, small hydropower and other emerging technologies. The Ministry of Non-conventional Energy Sources (MNES) is involved in the promotion for development, demonstration and utilization of these technologies, such as, solar thermal; solar photovoltaic; wind power generation and water pumping; biomass gasification/combustion/co-generation; small, mini, and micro hydro power; solar power; utilization of biomass, biogas, improved cook-stove; geothermal for heat applications and power generation/energy recovery from urban, municipal and industrial wastes; and tidal power generation. The commercialization of several renewable energy systems and products are currently underway. The MNES also deals with other emerging areas and new technologies, such as, chemical sources of energy, fuel cells, alternative fuel for surface transportation and hydrogen energy.

The global thrust on climate-friendly technologies is presently focused on climate change mitigation, such as fuel cell cars, biotechnologies, nano technologies to reduce electricity demand and CO_2 capture and storage. There is a growing need to develop technologies that reduce the vulnerabilities of developing and least developed country populations to adverse impacts of climate change. These technologies have to be low cost and be compatible with local environment and socioeconomic situations for faster adaptation . The revival of and building upon conventional wisdom, such as water management in arid and desert areas, weatherproof low-cost housing, and less water intensive night soil disposal, is also required. Modern technologies should augment the conventional wisdom for adapting to climate change. Various ministries and departments of the Government of India are engaged in technology development on diverse fronts that have been synthesized through the Technology Information, Forecasting and Assessment Council (TIFAC). The continuing work of scientists will remain crucial, generating the knowledge needed to develop effective responses to the challenges of climate change. North-South and South-South cooperation on climate change is a necessity, especially from the developing country perspective, as they need support for adaptation activities, and technology transfer.

CAPACITY NEEDS

Beyond the sectoral and scientific or technological capacity needs on climate change, the critical need in India is to integrate the diverse scientific assessments and link them with policy-making. Science has to provide objective scientific and technical advice to the policy-makers, especially for a complex process like climate change. While some experience of using integrated assessment models does exist in India, the capacity building in this area remains a double priority - first, to provide policy orientation to the scientific assessments and second, to provide robust scientific foundation to policy making. The development of assessment tools by interdisciplinary teams within developing countries is crucial. This would need commitment of sustained resources and institutionalization of multidisciplinary and networking efforts, within the scientific and policy-making establishments.

Climate change concerns, assessment challenges and response strategies, for diverse sectors and regions in India require an integrated assessment approach. Integrated assessment is an interdisciplinary process that combines, interprets, and communicates knowledge from diverse scientific disciplines from the natural and social sciences to investigate and understand causal relationships within and between complex systems. Integrated assessment attempts to present the full range of consequences of a given policy—economic or environmental, intended or unintended, prompt or delayed—in order to determine whether the action will make the society better or worse off, and by how much. It must be noted here that, integrated assessment is also not a monolithic, uniform, unique and universal model that can be applied to any context. It indicates an approach to policy-making that has to consider contextual issues and specific nuances of the sector under scrutiny to arrive at integrated policy assessment. For example, in deciding policy for water quality management in a particular place, integrated scientific advice should include the direct and indirect effects of urban development, agricultural run-offs, industrial pollution, and climate change-induced increase in heavy precipitation events on water resources, along with many other factors.

Networking is a critical requirement for integrated climate change assessments. The Initial National Communication project has made a beginning where more than a 100 inter-disciplinary research teams spread across the country have been networked together for a shared vision on climate change-related research. Such initiatives have to be strengthened. The participation of state and UT government departments is to be encouraged in climate change activities. This will build capacities at the state level for implementing policy measures such as those for reducing vulnerability of various sectors and communities , disseminating and promoting climate-friendly technologies and initiatives, adaptation, and energy efficiency improvements.

Finally, technology R&D, technology transfer and technology diffusion in India must be promoted. Since there are diverse disciplines involved in climate change, having a unified command and control regime may not be appropriate for these.

FINANCIAL NEEDS

The financial needs arise from the constraints detailed in the previous sections. They are necessary for research and actual projects for implementing climate change related policies and programmes. These cover diverse sectors and require considerable technology transfers and financial resources in terms of Article 4.3 of UNFCCC. Given the magnitude of the tasks, complexities of technological solutions and diversity of actions needed, the resources made available at present are wholly inadequate to address and respond to the requirements of the Convention.

The systems and policies in developing countries are not tuned to handle even the present climate-related stress and climate variability. Income disparities and population growth further constrain the opportunities and equitable access to the existing social infrastructure. The projected climate change could further accentuate these conditions. The challenge then is to identify opportunities that facilitate the sustainable use of existing resources. It entails considerations that make climate-sensitive systems, sectors and communities more resilient to current climate variability. This will pave the way to enhance their adaptive capacity to future climate change. Faster economic development with more equitable income distribution, improved disaster management, sustainable sectoral policies, careful planning of capital intensive and climate-sensitive long-life infrastructure assets are some measures that assist in ameliorating India's vulnerability to climate change.

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Annexures

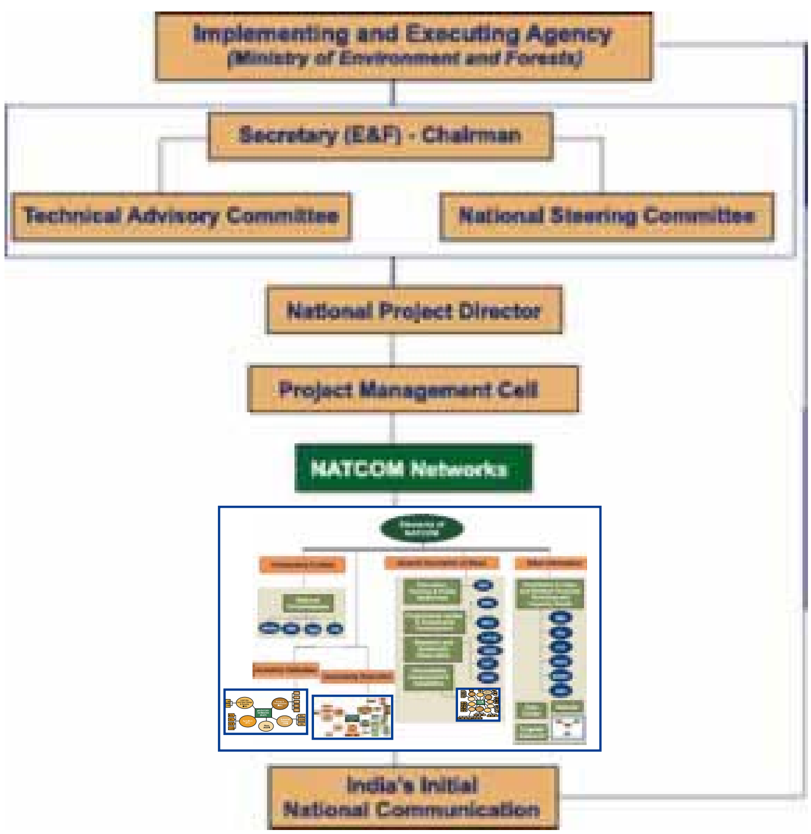
Annex-I

Implementation and Institutional Arrangements for the Preparation of India's Initial National Communication

The project on preparation of India's Initial National Communication to the UNFCCC has been implemented and executed by the Ministry of Environment and Forests (MoEF), Government of India. A National Steering Committee under the Chairmanship of the Secretary, MoEF, Government of India oversaw its implementation. A Technical Advisory Committee, advised on matters relating to the scientific and technical aspects of the various components of communication. A broad-based participatory approach involving 131 research teams from government ministries and departments, autonomous institutions and national research laboratories, universities, non-governmental organizations, industry associations, and private sector were involved in the process.

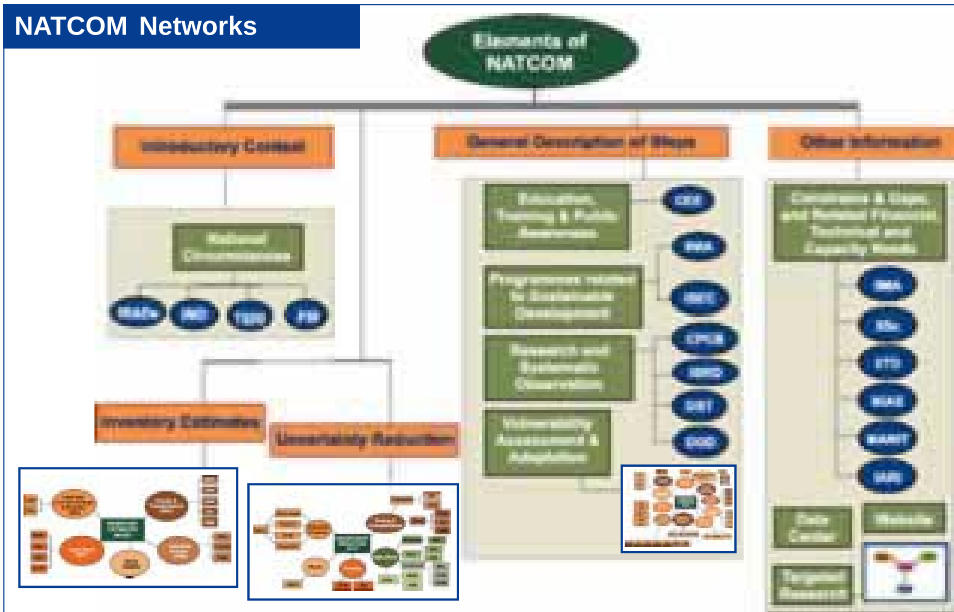
Being a Party to the Convention, India is required to furnish information in accordance with the provisions of the Convention for non-Annex-1 countries (Article 4 and 12), relating to implementation interalia to the development of a comprehensive national inventory of anthropogenic emissions by sources and removal by sinks of all GHGs not controlled by the Montreal protocol, elucidation of a general description of steps taken or envisaged for implementation of the Convention; and any other information relevant to the achievement of the objectives of the Convention and suitable for inclusion in its communication, including, if feasible, material relevant for calculation of global emission trends.

Implementation Arrangement



Institutional Mechanism

NATCOM Networks



CEE: Centre for Environment Education, Ahmedabad; **CPCB:** Central Pollution Control Board, New Delhi; **DOD:** Department of Ocean Development, New Delhi; **DST:** Department of Science and Technology, New Delhi; **FSI:** Forest Survey of India, Dehradun; **IARI:** Indian Agricultural Research Institute, New Delhi; **IIMA:** Indian Institute of Management, Ahmedabad; **IISc:** Indian Institute of Science, Bangalore; **IITD:** Indian Institute of Technology, Delhi; **IMD:** India Meteorological Department, New Delhi; **IRADe:** Integrated Research and Action for Development, New Delhi; **ISEC:** Institute for Social and Economic Change, Bangalore; **ISRO:** Indian Space Research Organization, Department of Space, Bangalore; **MANIT:** Maulana Azad National Institute of Technology, Bhopal; **NIAS:** National Institute of Advanced Studies, Bangalore; **TERI:** The Energy and Resources Institute, New Delhi

NATCOM Networks

Institutional networks were set up for GHG inventory estimation, measurement of emission coefficients, vulnerability assessment and adaptation (V&A), introductory context, general description of steps, other information including data center, website and targeted research. The institutional mechanisms for each of these were different and unique based on the requirements of the task. GHG inventory estimation required extensive sectoral data collection & validation, a framework of sectoral Lead Institutes supported by Participating Institutes was preferred. V&A required national level modeling for a macro view. These were conducted at premier national institutes under the guidance of prominent national experts. Independent case studies were also conducted to assess the broad canvas of V&A research requirements for a large country like India. For data center and website, the expertise available in the Indian software industry was used.

GHG Inventory Estimation

This component of the National Communication involved 19 research and development institutions, universities, and non-governmental organizations. The sectors considered include energy, industrial process, agriculture, landuse, land use change and forestry, and waste. Each of these sectors were coordinated by a lead institute and sub sectors under each had a number of participating institutes involved in the collection of primary and secondary activity data and preparation of GHG emission inventory for that sector.

All the participants have been trained through workshops on Inventory estimation and Good practices for reporting as per the IPCC guidelines. This includes the development of a Quality Assurance and Quality Control (QA/QC) plan. This approach was complemented by developing indigenous emission factors for some of the key sources of emissions in India. These are further expected to reduce the uncertainties in GHG estimates. Regular consultative meetings were conducted to reconcile the differences in top-down and bottom-up inventory estimates and other matters.

Institutional Network for Greenhouse Gas Inventory Estimation

CMA: Cement Manufacturers' Association, New Delhi; **CFRI:** Central Fuel Research Institute, Dhanbad; **CGCRI:** Central Glass and Ceramic Research Institute, Kolkata; **CLRI:** Central Leather Research Institute, Chennai; **CMRI:** Central Mining Research Institute, Dhanbad; **CRRI:** Central Road Research Institute, New Delhi; **DA:** Development Alternatives, New Delhi; **FRI:** Forest Research Institute, Dehradun; **FSI:** Forest Survey of India, Dehradun; **IARI:** Indian Agricultural Research Institute, New Delhi; **IIMA:** Indian Institute of Management, Ahmedabad; **IISc:** Indian Institute of Science, Bangalore; **IRPE:** Institute of Radio Physics and Electronics, Calcutta University; **NCL:** National Chemical Laboratory, Pune; **NEERI:** National Environmental Engineering Research Institute, Nagpur; **NPL:** National Physical Laboratory, New Delhi; **RRL:** Regional Research Laboratory, Bhubaneswar; **TERI:** The Energy and Resources Institute, New Delhi

Uncertainty Reduction in GHG Estimation

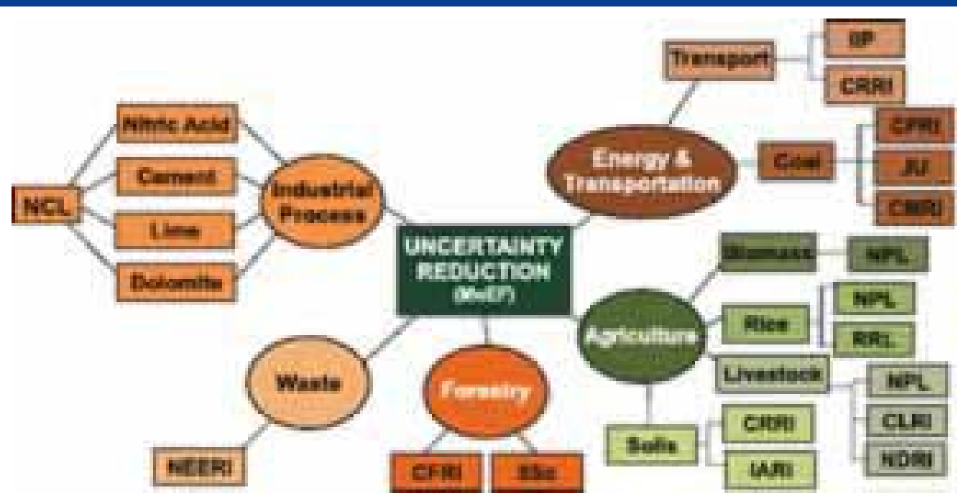
GHG emission estimates, based on IPCC default emission factors, are not ususally region or natural circumstances specific, and therefore have uncertainties in the emission estimates. Uncertainties also exist in the activity data. Through this project, an attempt has been made to generate India specific emission factors by undertaking in-situ measurements for some key source categories. The efforts were to define the range in uncertainties in the estimates through statistical methods. Time and budgetary resources available under the project limited the coverage under this activity.

The activities covered under the **energy sector** include measurement of CO_2 emission coefficients from coal based power, steel and cement plants representing different technologies. Some super thermal power plants, Integrated steel plants and medium sized cement plants were targeted for CO_2 emission coefficient measurement. Central Fuel Research Institute, Dhanbad and Jadavpur University, Kolkata conducted these measurements. Indian Institute of Petroleum, Dehradun measured the emission factors of CO_2, NO_x and NMVOC released from specific road vehicle categories operating on diesel and petrol. Central Road Research Institute, New Delhi used a combination of statistical methods and secondary data sources to reduce uncertainty in road transport sector activity data for 1994. Central Mining Research Institute, Dhanbad conducted measurements for methane emission coefficients from coal mining activity, where surface mining activities were measured for the first time in India.

Industrial processes included emission coefficient measurements from cement manufacturing process, lime production, and nitric acid production. The emission factor in case of cement manufacturing process is a product of CO_2 generated from CaO and MgO content of the clinker and the correction factor for CKD losses from the plant. This emission factor multiplied by the clinker production gives the emission of GHG from each cement plant. In the nitric acid production process, ammonia is oxidized with air to result in main products NO, NO_2 and a by-product N_2O in small quantities. After nitric oxides are absorbed, nitrous oxide is left out and is vented either directly or after using abatement technologies. National Chemical Laboratory, Pune conducted these measurements.

In the **Agriculture sector**, measurements were conducted for CH_4 emission coefficient estimation due to enteric fermentation in indigenous and crossbred dairy cows for different age groups. National Dairy Research Institute, Karnal conducted the experiments and National Physical Laboratory, New Delhi provided support for data measurement in terms of standardization of measurement and instrument calibration. The Indian Agricultural Research Institute, New Delhi was involved in the measurement of N_2O emissions from soils supporting rice – wheat systems in the country. They also conducted measurements to ascertain the

Institutional Network for Uncertainty Reduction in Greenhouse Gas Emissions



CFRI: Central Fuel Research Institute, Dhanbad; **CLRI:** Central Leather Research Institute, Chennai; **CMRI:** Central Mining Research Institute, Dhanbad; **CRRI:** Central Rice Research Institute, Cuttack; **CRRI:** Central Road Research Institute, New Delhi; **IARI:** Indian Agricultural Research Institute, New Delhi; **IIP:** Indian Institute of Petroleum, Dehradun; **IISc:** Indian Institute of Science, Bangalore; **JU:** Jadavpur University, Kolkata; **NCL:** National Chemical Laboratory, Pune; **NDRI:** National Dairy Research Institute, Karnal; **NEERI:** National Environmental Engineering Research Institute, Nagpur; **NPL:** National Physical Laboratory, New Delhi; **RRL:** Regional Research Laboratory, Bhubaneswar emission coefficient of N_2O due to application of nitrogenous fertilizers. National Physical Laboratory, New Delhi was involved in the measurement of N_2O and CH_4 emission coefficients from managed manure systems, CH_4 from rice cultivation under different water regimes and organic amendments, and CO_2, CH_4, N_2O, NO_x and CO from burning of crop residue.

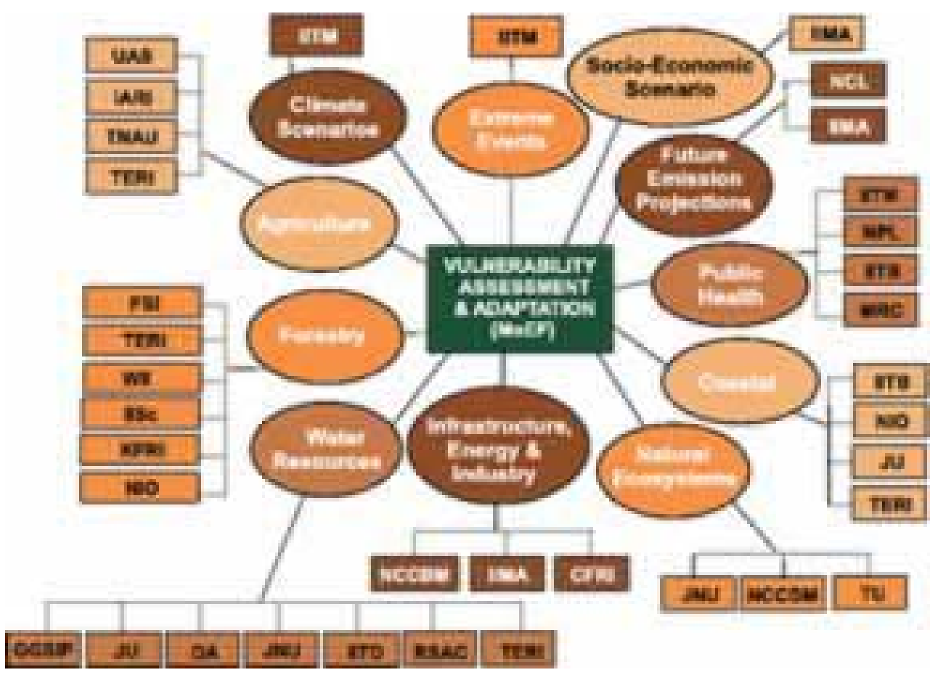
In the **Land Use Land Use Change and Forestry** sector, an attempt was made to assess uncertainty associated with activity data and emission factors. This covered determination of annual growth rate of plantations and different forest types, determination of annual growth of above ground biomass and measurement of soil carbon in various soil types. Indian Institute of Science, Bangalore coordinated these. A component on measurement of uptake of CO_2 by plants was conducted by Central Fuel Research Institute, Dhanbad.

In the **waste sector**, measurements were conducted to estimate the emission coefficient of CH_4 released from municipal solid waste dumping sites in New Delhi.

Vulnerability Assessment and Adaptation

It is generally agreed that the South Asian region, dominated by the monsoons, is one of the most difficult regions to model, with considerable differences among models and high sensitivity to model parameters. Based on the model projections, it is estimated that the mean surface temperature is projected to increase by 1.5-2.5 °C in Southern India while in the north it may increase by

Institutional Network for Vulnerability Assessment and Adaptation



CFRI: Central Fuel Research Institute; Dhanbad, **DA:** Development Alternatives, New Delhi; **FSI:** Forest Survey of India, Dehradun; **GGSIP:** Guru Gobind Singh Indraprastha University, Delhi; **IARI:** Indian Agricultural Research Institute, New Delhi; **IIMA:** Indian Institute of Management, Ahmedabad; **IISc:** Indian Institute of Science, Bangalore; **IITD:** Indian Institute of Technology, Delhi; **IITB:** Indian Institute of Technology, Mumbai; **IITM:** Indian Institute of Tropical Meteorology, Pune; **JU:** Jadavpur University, Kolkata; **JNU:** Jawaharlal Nehru University, New Delhi; **KFRI:** Kerala Forest Research Institute, Peechi; **MRC:** Malaria Research Centre, Delhi; **NCL:** National Chemical Laboratory, Pune; **NCCBM:** National Council for Cement and Building Materials, Ballabgarh; **NIO:** National Institute of Oceanography, Goa; **NPL:** National Physical Laboratory, New Delhi; **RSAC:** Remote Sensing Applications Centre, Lucknow; **TNAU:** Tamil Nadu Agricultural University, Coimbatore; **TERI:** The Energy and Resources Institute, New Delhi; **TU:** Tripura University, Agartala; **UAS:** University of Agricultural Sciences, Dharwad; **WII:** Wildlife Institute of India, Dehradun

2.5-3.5 °C by 2040. Given such complexities within India itself, the NATCOM project has attempted to identify regions of higher vulnerability to climate change in India, conducted a few specific studies and developed possible adaptation measures in a few sectors. However, time and budgetary resources available under the project limited the coverage under this activity as well.

Vulnerability assessments of the sectors carried out include **agriculture, water resources, forestry, coastal zones, natural ecosystems, human health, energy and infrastructure**. This exercise entailed the consistent construction of likely **climate** and **socio-economic scenarios** for India along with an assessment of **extreme events** using existing models and expertise.

Eleven activities have been identified for work under this component. Thirty-six research teams across the country have undertaken activities under the vulnerability assessment and adaptation component. Whilst the national sectoral studies were coordinated and synthesized by lead institutes, individual case studies were undertaken by different participating institutes.

Annex-II

Abbreviations

Acronyms	Expansion
AAR	Area Accumulation Ratio
ABER	Annual Blood Examination Rate
ADB	Asian Development Bank
ALGAS	Asia Least-cost Greenhouse Gas Abatement Strategy
An.	Anopheles
AOGCM	Coupled Atmosphere-Ocean General Circulation Models
API	Annual Parasite Index
ASSOCHAM	Associated Chambers of Commerce and Industry
BAPMON	Background Air Pollution Monitoring
C	Carbon
CADA	Command Area Development Authority
CAGR	Compounded Annual Growth Rate
CD	Cumulative Deaths
CDM	Clean Development Mechanism
CDPLP	Cumulative Deaths Per Lakh Population
CENPEEP	Centre for Power Efficiency and Environmental Protection
CERES	Crop Environment Resource Synthesis
CGMS	Crop Growth Monitoring Systems
CH_4	Methane
CII	Confederation of Indian Industries
CIMMYT	Centre for Maize and Wheat Research
CMA	Cement Manufacturers' Association
CMIE	Centre for Monitoring Indian Economy Pvt Ltd
CMRI	Central Mining Research institute
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
COP	Conference of Parties to UNFCCC
CPCB	Central Pollution Control Board
CRRI	Central Road Research Institute
CRZ	Coastal Regulation Zone
CSE	Centre for Science and Environment, New Delhi
CSIR	Council for Scientific and Industrial Research
CSIRO-Mk2	Commonwealth Scientific and Industrial Research Organisation Model
CTL	Control
DALYs	Disability-Adjusted Life Years
DBH	Diameter at Breast Height
DC	Data Centre
DDT	Dichloro-diphenyl-trichloroethane
DGVMs	Dynamic Global Vegetation Models
DJF	December, January, February
DKRZ	Deutsches Kilma Rechen Zentrum
DM	Dry Matter
DMMF	Dry Mineral Matter on Free Basis
DOD	Department of Ocean Development
DSSAT	Decision Support System for Agro-technology Transfer
DST	Department of Science and Technology
ECHAM	ECMWF forecast models, modified and extended in Hamburg

Acronyms	Details
EMC	Energy Management Centre
EMCP	Enhanced Malaria Control Programme
ENSO	*El-Nino* Southern Oscillation
ESI	Economic Survey of India
Esif	Emission Seasonal Integrated Flux Values
FACE	Free Air Carbon dioxide Enrichment
FICCI	Federation of Indian Chamber of Commerce and Industry
FOESS	Frequency of Severe Storms
FSI	Forest Survey of India
GAW	Global Atmospheric Watch
GCM	General Circulation Model
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIS	Geographic Information System
GOI	Government of India
GWP	Global Warming Potential
HadCM	Hadley Centre Model
HadRM	Hadley Centre Regional Model
HC	Hydrocarbons
HCV	Heavy Commercial Vehicles
HI	Housing Index
HTL	High-Tide Line
IA	Integrated Assessment
IAM	Integrated Assessment Models
IARI	Indian Agricultural Research Institute
IE	Inventory Estimation
IGCC	Integrated Gas Combined Cycle
IGIDR	Indira Gandhi International Development Research, Mumbai
IIMA	Indian Institute of Management, Ahmedabad
IIP	Indian Institute of Petroleum
IISc	Indian Institute of Science, Bangalore
IIT	Indian Institute of Technology
IITM	Indian Institute of Tropical Meteorology
IMD	India Meteorological Department
INDOEX	Indian Ocean Experiment
INFOCROP	Informatics on Crops
IPCC	Inter-governmental Panel on Climate Change
IREDA	Indian Renewable Energy Development Agency
IWRM	Integrated Water Resources Management
JFM	Joint Forest Management
JJA	June, July, August season
JJAS	June, July, August, September
KRCL	Konkan Railway Corporation Limited
LCV	Light Commercial Vehicles
LNG	Liquefied Natural Gas
LULUCF	Land Use, Land-use Change and Forestry
MAC	Methane Asia Campaign
MAM	March, April, May
MNES	Ministry of Non-conventional Energy sources
MoCM	Ministry of Coal and Mines
MoEA	Ministry of External Affairs
MoEF	Ministry of Environment and Forests
MoF	Ministry of Finance
MoHFW	Ministry of Health and Family Welfare

Acronyms	Details
MoR	Ministry of Railways
MoRTH	Ministry of Road Transport and Highways
MP	Montreal Protocol
MSL	Mean Sea Level
MSW	Municipal Solid Waste
N	Nitrogen
N_2O	Nitrous Oxide
NAMP	National Anti-Malaria Programme
NATCOM	National Communication
NBP	Net Biome Production
NCA	National Commission on Agriculture
NCAR	National Centre for Atmospheric Research
NGO	Non-Governmental Organisation
NHT	Northern Hemispheric Temperature
NMCP	National Malaria Control Programme
NMEP	National Malaria Eradication Programme
NO_x	Nitrogen Oxides
NPD	National Project Director
NPL	National Physical Laboratory
NPP	Net Primary Productivity
NSC	National Steering Committee
NTFP	Non-Timber Forest Product
NTPC	National Thermal Power Corporation
OECD	Organisation for Economic Cooperation and Development
OTC	Open Top Chambers
P.	Plasmodium
PC	Planning Commission of India
PCRA	Petroleum Conservation Research Centre
PDSI	Palmer Drought Severity Index
P_f CP	*Plasmodium falciparum* Containment Programme
PFT	Plant Functional Type
PIM	Participatory Irrigation Management
PMC	Project Management Cell
PNUTGRO	Peanut Crop Growth Simulation Model
PSUs	Public Sector Undertakings
PV	Photovoltaic
R&D	Research and Development
R&M	Renovation and Modernisation
RCM	Regional Circulation Model
SAIL	Steel Authority of India Limited
SEB	State Electricity Board
SHS	Solar Home Systems
SMD	Soil Moisture Deficit Ratio
SMI	Soil Moisture Index
SOI	Southern Oscillation Index
SPV	Solar Photo Voltaic
SRES	Special Report on Emission Scenarios
SSCL	Severe storms per km of the coastline
SST	Sea Surface Temperature
SWAT	Soil and Water Assessment Tool
T&D	Transmission and Distribution
TAC	Technical Advisory Committee
TAR	Third Assessment Report
TEDDY	TERI Energy Data Directory Year book
TERI	The Energy and Resources Institute

Acronyms	Details
TIFAC	Technology Information Forecasting and Assessment Council
TR	Targeted Research
UMB	Urea Molasses Block
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UR	Uncertainty Reduction in inventory estimation
VA	Vulnerability Assessment and Adaptation
VI	Vulnerability Indicators
WHO	World Health Organisation
WMO	World Meteorological Organisation
WOFOST	World Food Study Programme
WSSD	World Summit on Sustainable Development
WTGROWS	Wheat Growth Simulator

Units and quantities

BCM	Billion Cubic Meter (equals 1km^3)
BCM	Billion Cubic Metre (equals 1km^3)
C	Celsius
Gg	Giga gram
GW	Giga Watt
GWh	Giga Watt hour
ha	Hectare
hPa	hecta Pascal
ka	Kilo annual
km	Kilometre
km^2	Square kilometre
km^3	Cubic kilometer
kW	kilo Watts
kWp	kilo Watts peak
M	Million
m^3	Cubic metre
Mha	Million hectare
MJ	Mega Joule
mm	millimeter
Mt	Million tonne
Mt-CO_2	Million tonnes of Carbon dioxide
Mt-CO_2	eqMillion tonnes of Carbon dioxide equivalent
MW	Mega Watts
ppb	parts per billion by volume
ppm	parts per million by volume
ppt	parts per trillion by volume
t	ton
Tg	Tera gram
TJ	Tera Joule
toe	tons of oil equivalent
tons/cap	tons per capita
W/M^2	Watt per square metre

Conversion table

1Giga gram (Gg)	=	1000 tonnes
	=	10^9 g
1Tera gram (Tg)	=	1 Million tonnes
	=	1000 Gg
	=	10^6 tonne
	=	10^{12} g
1 Tera Joule (TJ)	=	10^3 GJ
	=	10^{12} Joules
1 Calorie	=	4.18 J

Annex-III

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Annex-IV

Events for Education, Training and Public Awareness

2001

- *Inception workshop for India's Initial National Communication to the United Nations Framework Convention on Climate Change*, 22 November 2001, New Delhi, 87 participants
- *Seminar on Climate Change: Issues, Concerns and Opportunities*, 23 November 2001, New Delhi, 53 participants
- *Targeted Research on Climate Change in India*, 26 November 2001, New Delhi, 48 participants
- *Workshop on Good Practices in Inventory Development*, 27-30 November 2001, New Delhi, 80 participants
- *Seminar on Reducing Uncertainties in Inventory Estimates,* 28 November 2001, New Delhi, 24 participants
- *Workshop on Inventory Development*, 3-5 December 2001, Ahmedabad, 41 participants
- *Workshop on Future Socio-economic Scenario Generation and Emission Projections*, 6-7 December 2001, Ahmedabad, 30 participants
- *Workshop on Climate Change: Impact Assessment, Vulnerability and Adaptation Strategies*, 17-19 December 2001, Kolkata, 55 participants

2002

- *National Communication workshop on Inventory Development, Uncertainty Reduction, and Vulnerability Assessment and Adaptation Strategies – Forestry Sector*, 7-8 February 2002, Bangalore, 30 participants
- *Vulnerability Assessment and Adaptation workshop*, 6 March 2002, New Delhi, 17 participants
- *National Seminar on Global Warming and Our Water Resources,* 14-15 April 2002, Kolkata, 67 participants
- *National Seminar on Vulnerability of Sundarban Mangrove Ecosystem in the Perspective of Global Climate Change*, 14-15 June 2002, Kolkata, 55 participants
- *Conference on Climate Change and Industry: Issues and Opportunities*, 13 July 2002, Chennai, 82 participants
- *Conference on Climate Change: Issues and Opportunities*, 11 September 2002, Guwahati, 180 participants
- *Inventory Estimation workshop*, 12 September 2002, New Delhi, 18 participants
- *Workshop on Uncertainty Reduction in GHG Inventory,* 8-9 October 2002, New Delhi, 32 participants

2003

- *Workshop on Other Information*, 15 February 2003, Bangalore, 11 participants
- *Workshop on Finalization of Emission Coefficients Derived from Uncertainty Component of NATCOM,* 4-5 March 2003, New Delhi, 30 participants
- *Workshop on Finalization of GHG Emission Inventories***,** 27 March 2003, New Delhi, 35 participants
- *Workshop on Synthesis of Vulnerability Assessment and Adaptation Studies and Future Climate Change Research Needs***,** 28 March 2003, New Delhi, 26 participants
- *Workshop on Finalization of GHG Emission Inventories from Agriculture sector***,** 2 April 2003, New Delhi, 11 participants
- *Workshop on Finalization of GHG Inventory in Landuse, Landuse Change and Forestry Sector*, 6-7 May 2003, Dehradun, 16 participants
- *Vulnerability Assessment and Adaptation workshop on Water Resources, Coastal Zones and Human Health,* 27-28 June 2003, New Delhi, 30 participants
- *Vulnerability Assessment and Adaptation workshop on Agriculture, Forestry and Natural Ecosystems,* 18-19 July 2003, Bangalore, 40 participants
- *Workshop on Scenarios and Future Emissions*, 22 July 2003, Ahmedabad, 25 participants

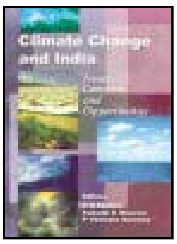
2004

- *Consultation Meeting on Climate Change and India: Uncertainty Reduction in GHG Inventory Estimations,* 12 February 2004, New Delhi, 18 participants
- *National Workshop on India's Initial National Communication,* 26 March 2004, New Delhi, 125 participants

Annex-V

Publications under the Aegis of India's Initial National Communication

Books



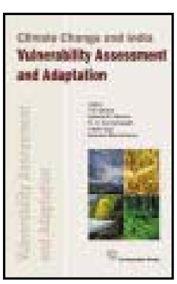
Climate Change and India: Issues, Concerns and Opportunities

A Tata McGraw Hill Publication, Delhi, 2002

Editors:
P. R. Shukla
Subodh K. Sharma
P. Venkata Ramana

India's commitment to the United Nations Framework Convention on Climate Change is reflected in the various initiatives which have been taken at the national level for sustainable development and climate change. Environmental protection and sustainable development have emerged as key national priorities and manifest in India's planned approach to socio-economic development and poverty eradication. Conservation and resource management are integral to the country's development plans. A sound environmental policy and law framework is also in place. Recent economic liberalization policies have seen new strides in technology upgradation, cleaner fuels, efficiencies in production and environmentally sound practices. At the same time, Indian society's traditional respect for the ecology, rivers and nature remains as strongly rooted as ever in the country's quest for sustainable and climate friendly development.

Ministry of Environment and Forests, Government of India organized a seminar at New Delhi to articulate the issues, concerns and opportunities for India resulting from climate change. Eminent experts were invited to contribute papers towards this objective. The book consolidates the papers presented at the seminar. The themes included integrated perspectives on climate change in terms of GHG inventory status and projections; sustainable development issues; climate change impacts and adaptation for India; climate change and Indian forestry and agriculture sectors; mitigation options using renewable energy technologies; and challenges, opportunities and responses of the Indian industry vis-a-vis climate change.



Climate Change and India: Vulnerability Assessment and Adaptation

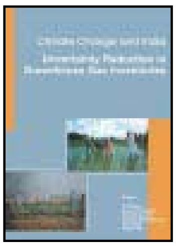
A Universities Press Publication, Hyderabad, 2003

Editors:
P. R. Shukla
Subodh K. Sharma
N. H. Ravindranath
Amit Garg
Sumana Bhattacharya

The global scientific assessments present the picture of a warming world and other changes in the climate system. There is increasing evidence to attribute the warming to human activities, which will continue to change atmospheric composition throughout the 21st century. This book provides assessments of the impacts, vulnerabilities and adaptation needs for the key economic and ecological sectors of India. The assessments are undertaken keeping in view the regionally disaggregated projections of climate change over the Indian sub-continent. The sectors assessed include water, agriculture, forestry, eco-systems, health, coastal zones, energy and infrastructure. The complexity of the assessments in India derives from geographical diversity, close interface of economy and culture with monsoon, diverse and unique ecosystems, rising trends of population and economy, and relative scarcity of natural resources compared to growing demand. The book includes the state-of-the-art assessments by recognized

Indian experts from diverse disciplines. The four key contributions of the book are: first, the use of formal assessment tools under developing country contexts; second, the articulation and quantification of climate change and emissions scenarios for India; third, the consistency of assessments vis-à-vis future climate change projections; and fourth, the focus on development for delineating conclusions and tasks. The contents of the book shall be of interest to policy-makers; researchers and modelers engaged in impact assessment; global environmental assessment programs and development experts. The book is an excellent addition to the growing literature on global environmental assessment methodology, policies and perspectives.

Climate Change and India: Uncertainty Reduction in GHG Inventories (jn press)



A Universities Press Publication, Hyderabad, 2004

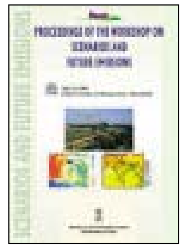
Editors:
A. P. Mitra
Sukumar Devotta
Subodh Sharma
Sumana Bhattacharya
Amit Garg
Kalyan Sen

The critical factors on which the reliability of GHG inventory depends are emission coefficients and activity data used. The reliability of the activity data depends on the sources from where it is derived and the statistical reliability of the sampling made to ascertain the total activity in a country. Similarly, country-specific emission coefficients representing indigenous conditions are more appropriate for use for developing a national inventory. Considering these concerns, an effort was made under the aegis of India's Initial National Communication, to reduce uncertainty in GHG inventory estimates from the country. Measurements were conducted to derive GHG emission coefficients for some key source categories that contribute significantly to the total national GHG inventory. These include determination of NCV of different types of coal in India, CO_2 emission coefficients for the cement manufacturing process, GHG emission from transport sector, CH_4 from fugitive emissions in coal mining, N_2O emission from nitric acid production, CH_4 emissions from agricultural activities such as rice cultivation and enteric fermentation and CH_4 from solid waste management. The activity data which have been closely scrutinized for reducing uncertainty include allocation of fuel in the road transport sector and activities related to the land use and land cover change and forestry sectors. This book synthesizes sectoral papers contributed by participating experts and also suggests future activities that will help in strengthening India's emissions inventories further. The effort, considering the limited time available was remarkably extensive and productive.

Workshop proceedings

Proceedings of the NATCOM workshop on Vulnerability Assessment and Adaptation due to climate change on Water Resources, Coastal Zones and Human Health
June 27-28, 2003, Delhi

Proceedings contain the results of the investigations in the sectors water resources, coastal zones and human health. The proceedings include papers on impact of climate change on Chhota Shigri glacier, Chenab basin and Gangotri glacier, Ganga headwater in the Himalaya; ground water resources of Deccan Besalt and Ganga basin; malaria in India with emphasis on selected cities; impact of sea level rise on surface inundation and salt water intrusion in Goa; biogeochemical modeling studies of the Achankovil river basin; vulnerability assessment and adaptation for water sector, sea level rise along the Coast of India; lower Ganga-Brahmaputra-Meghna Basins, assessment of climate drivers controlling malaria, Sundarban island system; and increasing community resilience for adaptation to adverse impacts.

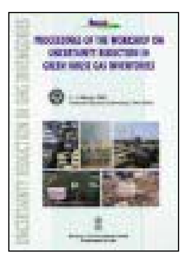


Proceedings of the NATCOM workshop on Scenarios and Future Emissions
July 22, 2003, Ahmedabad

Proceedings contain the results of the investigations for climate and emission scenarios and future green house gas emissions. The proceedings include papers on national circumstances for a sustainable future; regional climate change scenarios; future scenarios of extreme rainfall and temperature, emission scenarios and CO_2 emission projections; estimation of present and future emissions of HFCs, PFCs and SF_6 from Indian industry; future methane and N_2O emissions; impacts of climate change on energy, industry and infrastructure.

Proceedings of the NATCOM workshop on Vulnerability Assessment and Adaptation due to climate change on Agriculture, Forestry and Natural Ecosystems
July 18-19, 2003, Bangalore

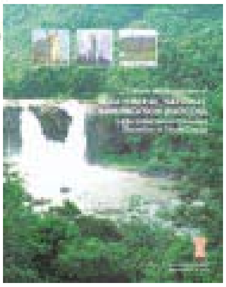
Proceedings contain the results of the investigations in the sectors agriculture, forestry, and natural ecosystems. These include papers on impact of enhanced CO_2 concentration on crop growth; assessment of impacts of climate change on crop yields; irrigated and rainfed crop production systems; forests; mangrove forests along the southern west coast; meadows and mountain ecosystems; marine ecosystems; natural ecosystems; lotic ecosystem; Garhwal Himalayan forests; wet evergreen and shola forests of Kerala; Kachchh district of Gujarat; case study of sequestration of carbon through afforestation; and GIS based evaluation of climate change impacts on hydrology.



Proceedings of the NATCOM Workshop on Uncertainty Reduction in GHG Inventory Estimates
March 4-5, 2003, Delhi

Proceedings contain papers on uncertainty reduction in estimation of greenhouse gas inventories from coal fired power plants & integrated steel plant; thermal power plants; coal mining and handling activities; road transport sector; rice fields; CO_2 emissions in cement plants; lime production process; dolomite mineral use; N_2O emission coefficient from nitric acid production; rice cultivation; CH_4 and N_2O emission from flooded rice soils; CH_4 emissions from livestocks; CH_4 and N_2O emission from agricultural soils; field burning of agricultural crop residue; CH_4 emission from municipal solid waste landfills; quality assurance, and the LULUCF sector.

Brochures



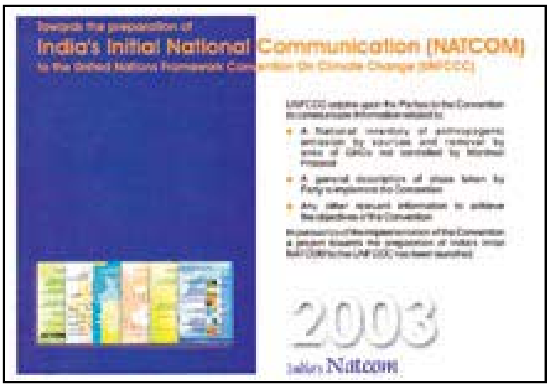
Towards the preparation of India's Initial National Communication (NATCOM) to the United Nations Framework Convention on Climate Change
June 2002

Towards the preparation of India's Initial National Communication (NATCOM) to the United Nations Framework Convention on Climate Change
November 2002

A Compendium of Activities: India's NATCOM on the World Wide Web
May 2003

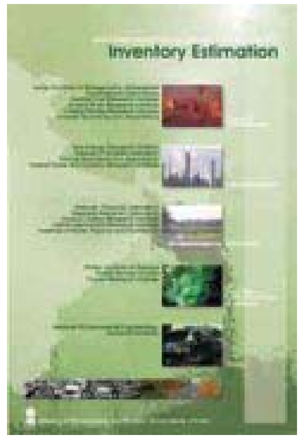
India's Initial National Communication (NATCOM) to the United Nations Framework Convention on Climate Change
November 2003
Publicity material

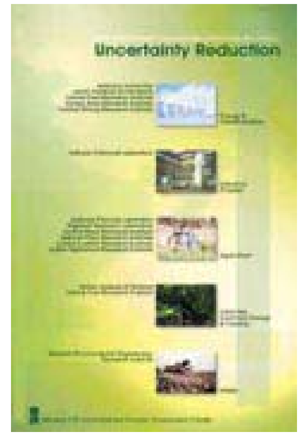
Calendar 2003



Posters


Implementation Arrangements


Inventory Estimation


Uncertainty Reduction


PROCEEDINGS OF THE WORKSHOP ON
VULNERABILITY ASSESSMENT AND ADAPTATION
DUE TO CLIMATE CHANGE ON INDIAN WATER
RESOURCES, COASTAL ZONES AND HUMAN HEALTH
WATER RESOURCES, COASTAL ZONES AND HUMAN HEALTH


Capacity Building Initiatives
Events


NATCOM Network


Towards the preparation of
India's Initial National Communication (NATCOM)
to the United Nations Framework Convention on Climate Change
Objectives
Implementation