“Working Together to Respond to Climate Change”
Annex I Expert Group Seminar in Conjunction with the OECD Global Forum on Sustainable Development

India

Country Case Study on Domestic Policy Frameworks for Adaptation in the Water Sector

Dr. Bharat R Sharma and Peter G McCornick

International Water Management Institute

Background information for presentation to be given by Bharat Sharma at the Annex I Expert Group Seminar in Conjunction with the OECD Global Forum on Sustainable Development on 28 March 2006

March 2006

Water Resources and their Use

India faces a turbulent water future. The country has a highly seasonal pattern of rainfall, with 50% of precipitation falling in just 15 days and over 90% of river flows occurring in just four months. The Indian mainland is drained by 15 major (drainage basin area >20,000 km^2), 45 medium (2,000 to 20,000 km^2) and over 120 minor (<2,000 km^2) rivers, besides numerous ephemeral streams in the western arid region. For large-scale analysis of water-resources, the country is often separated into some 19 major drainage regions (NCIWRDP, 1999; Amarasinghe et al; 2005). The Indus, and Ganga-Brahamputra-Meghna systems cover, respectively, some 10 and 35% of the entire country, and are characterized by extensive flood plains and deltas. There is considerable spatial variation in mean annual precipitation, which ranges from about 100 mm in western Rajasthan to more than 2500 mm in northeastern areas with a world maximum of 11,000 mm near Cherrapunji. This coupled with a variety of geological and topographical conditions within a given basin results in a large spatial variability of flow regimes ranging from regimes partially fed by snowmelt in the rivers originating from Himalayan mountains, to regimes of alluvial plains rivers, which receive considerable base flow from groundwater in the autumn (Bandyopadhaya, 1995). These rivers play a major role in the economy of India through sustaining agriculture, industry, and energy generation and by providing ecological services.

The average annual precipitation in India in volumetric terms is 4,000 billion cubic meter (BCM). The average annual surface flow from this is 1,869 BCM, the rest being evaporated or infiltrated. Due to topographical and other constraints, it is estimated that only 690 BCM can be effectively utilized. The annual replenishable groundwater resources in the country are estimated at 432 BCM. The total ultimate irrigation potential of the country has been estimated at 140 m ha (58.5 million ha from surface water and 81.5 m ha from groundwater). By trans-basin diversions, it is estimated that a further 25 m ha potential can become available through surface and 10 m ha through groundwater sources.

Irrigation constitutes the main use of water and presently accounts for 84% of the total water withdrawals. The share of per-capita withdrawals by the domestic and industrial sectors is some of the lowest in the developing world (59 m^3 per person in India compared to 132 m^3 per person in China, World Bank, 2005). Environmental water needs like minimum flow in the rivers, water for wetlands/ mangroves and recreation receive an even smaller share. However, with increasing urbanization and per-capita demand, the water demands of domestic, industrial and other sectors are expected to increase and become highly competitive with the irrigation sector. Acceptable minimum river flows during low flow months may have to be met from already developed water resources (Rao and Sinha, 1991; Smakhtin et al; 2004). The available surface water storage in existing major and medium projects in the country is 177 BCM. Projects under construction are likely to add another 75 BCM. The contribution expected from projects under consideration is 132 BCM. To date, the country has completed construction of 124 major and 708 medium projects with a total investment of INR 1,55,625 billion (approximately $US 3,500 billion). An expenditure of INR 404.3 billion (approximately $US 9 billion) was made in minor irrigation up to 1997. Due to inadequate dam storage capacities and poor maintenance of the public irrigation infrastructure, contribution of public surface irrigation has been on decline. Presently, about 60-

65 per cent of the irrigation and about 90 per cent of domestic and industrial water requirements are met through private groundwater resources (Sharma, Scott and Shah, 2004). This ground water development is purely through the individual initiatives (except some credits from financial institutions) and there are little regulations for abstraction of the groundwater. Much of the groundwater developments are characterized by relatively numerous and lower yield wells, even in comparison to other developing countries such as China. As will be discussed below, this is particularly challenging to regulate.

Perhaps more than anywhere, with its geographical and cultural diversity, and the demands placed by a fast growing economy and increasing population, these challenges are particularly acute in India. Several factors influence India's future water supply and demand. These include spatial variation and future growth of the population, urbanization and growing income levels and changes in food habits (higher consumption of animal-based products); growth in crop yields, cropping intensity and groundwater use; potential of rainfed agriculture and future growth in industrial and environmental water demand and internal and international food trade. National Commission on Integrated Water Resources Development (NCIWRD) of India has estimated the country's potentially utilizable water resources at 1022 km^3 (690 km^3 from surface water and 432 km^3 from groundwater). Total water use in the country was estimated at the level of 611 km^3 in 2000 and projected to 793 km^3 in year 2025 and 1104 km^3 during 2050. These water demand projections are based on the population projections at the level of 1581 million by 2050. With competing and evolving demands, and declining per capita availability of renewable water, India is faced with turbulent times ahead if these demands, including the needs of the poor, are to be met or even maintained.

Institutional Arrangements

The institutional environments of water institutions in India have evolved through a long process. But, with the consolidation of a centralized government bureaucracy and the spread of markets and commercialization, local and community-centered institutions have lost their relevance and gradually disappeared. The Union Ministry of Water Resources (MOWR) is the national organization that is responsible for overall planning and management of the water resources in the country. The Central Water Commission (CWC), the Central Ground Water Board (CGWB) and the National Water Development Agency (NWDA) – all under the MOWR – provide the overall monitoring and technical support whereas the research and training support is provided by state level Water and Land Management Institutes, Indian Council of Agricultural Research (ICAR), a large number Universities and other national and international research organizations. The Planning Commission at the national level provides project clearance and approves financial allocation to various water (irrigation/ hydropower/ multipurpose) projects in different states. However, given that 'water resources' are a state subject under the constitution, the actual legislative and managerial responsibilities are with the public works, irrigation, or water resources departments at the state level. There are also important organizational arrangements to achieve inter-state and center-state coordination. These include various river boards created under the River Boards Act of 1956 and the National Water Resources Council (NWRC) set up in 1983, and the National Water Board (NWB) set up in 1990. The NWRC is an important policy organ in the Indian water sector as it is the apex body chaired by the Prime Minister and includes the Union Minister of Water Resources and the Chief Ministers of each state. The NWB –

considered as executive arm of NWRC is chaired by the Secretary of MOWR and includes the Chief Secretaries of all the states, secretaries of the concerned Union ministries as well as the Chairman of CWC. While state irrigation departments have a larger role in the provision and management of public irrigation systems, local governments such as municipalities and *panchayat* (village council) also play an important role in drinking water supply. In larger cities and towns, water for drinking and some other pressing needs is also supplied by small private contractors (though at exorbitant costs) especially during summer months when municipal supplies fall much short of the soaring demands. Pollution control boards set up both at the center and in the states have the responsibility for water quality aspects (Saleth 2004).

As water is a state subject, it is the states that are responsible for financing, cost recovery and management of surface irrigation and water supply related activities within their territory. Even though the states have the major responsibility for water sector financing, the center government also plays a significant role by providing finances to states through central assistance, undertaking the construction of irrigation projects of national importance and implementing schemes such as the ‘Command Area Development’ (developed mainly for improving productivity in canal command areas through various on-farm development activities) in canal regions. In many states the administration and functional responsibilities for managing water resources are unclear and spread over a number of different government institutions (irrigation/ water resources departments, public works department, revenue departments, groundwater boards, minor irrigation and tubewell corporations, pollution control boards, municipal corporations etc.), making it particularly difficult to develop an integrated approach to water management. As with many countries, water administration is based on administrative boundaries and projects rather than on hydro-geological/water basin boundaries. This gives rise to several water sharing disputes among the states sharing a common river or other water resource.

Over the years, India has developed a relatively sound technical information base and expertise in many aspects of water development and management. However, the effective application of this information and knowledge at the practical level is constrained by a number of factors including absence of appropriate organizational arrangements for enforcement and monitoring. The existing regulatory mechanisms and their application for both surface and groundwater resources are inadequate to generate incentives to enhance water use efficiency. Irrigation water made available through surface irrigation systems has extremely low or zero water charges with no reliability, groundwater is an easement to the land property rights, and energy used for pumping groundwater is also highly subsidized and even free in several states. This leads to a very poor appreciation of the real value of water and poor availability of funds for maintenance and operation of the irrigation infrastructure and modernization of the energy utilities. Various arrangements exist for resolving conflicts at various levels in India. Prioritization of water use specified in the National Water Policy and implied in the constitution provides a general framework for resolving inter-sectoral water allocation conflicts. In the case of inter-state water sharing conflicts, the frequently relied on arrangement involves negotiated agreements for sharing or developing the water resource. But, when negotiated agreements fail or there is difficulty in reaching a negotiated settlement, the concerned parties can rely on the tribunals established by the government under the provisions of the Inter-state Water Disputes Act of 1956

(Iyer, 1999). Micro-level water conflicts may be resolved through informal/traditional village level institutions, formal village councils and water user associations.

Water Institutions at Local Level

Informal or traditional water rights for individuals and groups have existed in India since ancient times and continue (in a much weaker form) even today. Tank irrigation systems of South India (Vani, 1992); the 200-year old *Phad* system, *Shejpali* (water distribution roaster system) and *Pani Panchayat* (water council) system in Maharashatra (Thakur and Patnaik, 2002) have been quite successful. These are all community managed water distribution systems where the available water resource is distributed among all its members through well-accepted norms. Water council is a group of village elders (elected or nominated), which help in resolving water related conflicts at the village level. Several other forms of cooperatively operated and community-managed irrigation activities exist for lift irrigation schemes and small water-harvesting structures in mountainous and water deficit areas. Creation of Watershed Association is also a very important tenet under all the center; state and NGOs sponsored watershed management programs currently under implementation in the country. Watershed associations along with the watershed professionals develop the watershed development plans, implement the community-agreed plans and have the responsibility of operation and maintenance of the structures and other components during and after the completion of the project. Water rental markets in the rural areas contribute both to equity and better utilization of irrigation assets. In this system a person with a surplus capacity of the resource/ irrigation structure rents out the structure/ resource to the neighboring farmers. The expanding phenomenon of pump set rentals for pumping groundwater from the wells is an indication of the existence of surplus pumping capacity; particularly in the case of diesel pump sets. The root cause to the sub-optimality (not fully utilizing the pumping capacity of the pumps due to small and fragmented farming holdings) of these groundwater markets lies not so much in their economic and organizational aspects but in the legal and institutional vacuum within which they operate at present (Saleth, 2004).

From the perspective of institutional performance, the existing local institutions and large public institutions, particularly those related to inter-basin transfers, inter-sectoral allocations, and conflict resolution, are too weak to address the problems like water distribution and allocation, charging and collecting water and energy fees, operation and maintenance of irrigation infrastructure, regulation of water abstraction and ensuring water quality standards. The institutions also need to be made more effective for resolution of conflicts at various levels and regulation and enforcement of the policies.

Legal Framework

India does not have any separate and exclusive water law, but there are water–related legal provisions dispersed across various irrigation acts, central and state laws, provisions in the constitution, orders/decrees of courts, customary laws, and various penal and criminal procedure codes. As most of the water related legal provisions enacted in the past were characterized by water surplus conditions, they fail to reflect the current conditions of increasing water scarcity. Important features of the laws and regulations that govern water supply and management at different levels include the following.

i. As per the Entry 17 in the State list under the seventh schedule of Indian Constitution of 1952, it is the states that have jurisdiction over water resources within their borders. However the powers of the states are subject to Entry 56 with the Union List that allows the central government to regulate and develop inter-state rivers and river valleys when this is declared by parliament as a matter of public interest.
ii. The central government has regulatory roles in the water sector vide Article 252 related to inter-state water projects as well as through the Forest Conservation Act of 1980, which stipulates that the States obtain environmental clearance before executing projects in ecologically sensitive areas.
iii. The central government also has an important role in resolving inter-state water disputes as per the provisions under Article 262. Under the inter-state Water Disputes Act of 1956, a number of tribunals were set up to resolve water disputes among the states. Despite these legal provisions, the final legislative powers are still with the states in the sense that constitutionally speaking, water related laws could be passed only by or with the support of the state legislature.
iv. India also does not have any explicit legal framework specifying water rights. But the Easement Act of 1882 made all rivers and lakes the absolute right of the state. Individual rights to both surface water and groundwater are recognized only indirectly through land rights. As per the provision of transfer of the Property Act of 1882 and the Land Acquisition Act of 1894, a landowner can have a right to groundwater as it is considered as an easement of the land. So the landowners own the groundwater on their lands. The legal aspects governing groundwater resources continue to remain largely divorced from both resource sustainability and economic requirements (Jain, 1976). In the case of canal water, the rights of access are limited only to those having access to land in canal command areas and these rights are only use rights and not ownership rights.
v. Certain provisions of the penal codes can be used to penalize users for non-payment of water/electricity charges or illegal water diversions from canals. Water charges for irrigation services are fixed by irrigation/ revenue departments of the state and depend upon the crop and area to be irrigated. These charges are very low and vary from USD 2 to USD 10 (sugarcane, paddy) per hectare per season for different crops and among different states. Several states have even abolished these charges and in others the collection rates are very low. There are no corresponding provisions to ensure accountability of service providers for their failure to supply water at the right time or in required quantity. Yet, certain informal mechanisms such as water user associations and stakeholder based basin organizations could ensure accountability and quick dispute resolution besides inducing efficient water use. Water charges for domestic and industrial uses are fixed by local institutions (municipal corporations, village/ town councils) and are generally based on volumetric metering.

Saleth (1994 & 2004) argues that the benefits of creating a water rights system can outweigh the cost of transacting this institutional change.

Water Policy

Following the unprecedented drought of 1987, the Union Ministry of Water Resources (MOWR) formulated India's first National Water Policy (NWP, 1987). Signifying the start of a process intended to improve the management of the Nation's water resources, the NWP laid out the approaches of the Central and State Governments on water resources planning, development, allocation and management. The NWP included the conjunctive use of water from surface and sub-surface resources, supplemental irrigation and water conserving crop patterns, and irrigation and production technologies. Since all the surface water in the irrigation systems is supplied through state owned canal systems at very low rates, it also recommended higher tariffs for canal water and establishment of water user associations for efficient farm-level water management. The NWP did not suggest any major economic and institutional changes for better management of the resources and soon became redundant. A new NWP was declared in 2002, which in addition to the earlier provisions recognized the role of private sector participation and the need for a paradigm shift from resource development to efficient utilization of the developed resources. However, it did not fully incorporate the current level of thinking with regards to effective basin management. This policy also failed to address the economic and institutional issues that are constraining the water sector in India such as acute scarcity of funds for renovation/ repairs of a deteriorating irrigation infrastructure and funds for completion of a large number of on-going irrigation projects. For instance, much of the public irrigation investments in India are primarily viewed as instruments for fostering socio-economic development, especially by augmenting income, employment and food production, rather than the economic return. The selection criterion is quite liberal with internal rate of return (IRR) of 7% for projects in drought prone and water scarce areas and 9% in other areas whereas the prevailing rate of interest is higher than 10%. Moreover, the state governments seldom pay funds received from the central government in the form of grants back.

The prevailing cost recovery and water-pricing policies fail to capture and convey the scarcity value of the resource and induce discipline and efficiency in its use. The Committee on Pricing Irrigation Water recommended the recovery of not only full O&M costs and one percent capital cost, but also a percentage of the depreciation cost. Unfortunately, the recovery policy, despite its widespread approval was never implemented, (mainly due to political considerations) as it recommended an upward revision in water rates and a radical change in the method of its determination.

The adoption of the concept of participatory irrigation management in canal command areas has also remained relatively ineffective in India. More recently, the financial crises and physical degradation of the irrigation systems have forced the irrigation agencies to consider WUAs as indispensable partners in irrigation management. As a result, the farmers' role in outlet level water allocation, fee collection and system maintenance was recognized (Vermillion, 1997). States of Andhra Pradesh and Madhya Pradesh have enacted special laws to facilitate large-scale turnover program of canal irrigation to WUAs. In several new and upcoming irrigation projects, it is categorically specified that water will be distributed only to organized WUAs. To overcome the impacts of declining irrigation investment and poor financial performance of water projects a special committee has further recommended for a gradual, selective and stage-wise progress of privatization of the irrigation sector (GOI, 1995). The NWP (2002) has also encouraged the reliance on the private corporate sector as a potential partner for water resources development and management. But a suitable working model has not yet developed for either a public-private partnership or a private agency taking over the public managed system.

Impact of Climate Change on Water Resources

The Indian sub-continent is bounded on the north by the Himalayas and on the south by the Indian Ocean. Based on broad climatic features, the northern mountainous region has a near temperate climate, the central and western region have arid and semi-arid climates and the southern region is under the influence of a tropical climate. The regional climate is influenced predominantly by the monsoons. The spatial range of temperature is significantly large during the winter. Extreme temperatures of over 45˚C occur over the northwest part of the country during May-June. The warming trend over India has been reported to be 0.57˚C per 100 years (Rupakumar et.al. 1994).

Approximately 70% of the total annual rainfall over the subcontinent is confined to the southwest monsoon season (June-September). The western Himalayas get more snowfall than the eastern Himalayas during winter. There is more rainfall in the eastern Himalayas than the western Himalayas during the monsoon season (Kriplani, et.al, 1996). Recent decades have exhibited an increase in extreme rainfall events over northwest India during the summer monsoon (Singh and Sontake, 2001). Moreover, the number of rainy days during the monsoon along the east coast stations has declined in the past decade.

Extreme Climatic Events

Apart from intra-seasonal and intra-annual variability in climate, extreme weather events such as heat and cold waves, tropical cyclones, prolonged dry spells, intense rainfall, tornadoes, snow avalanches, thunderstorms and dust storms are known to cause adverse effects in widely separated areas of Asia (Karl et. al., 1995). Permanent glaciers in the upper Himalayas have vacated large areas during the past few decades, resulting in an increase in glacial runoff. As a consequence, an increased frequency of events such as mudflows and avalanches affecting human settlements has occurred (Rai, 1999). As mountain glaciers continue to disappear, the volume of summer run-off eventually will be reduced as a result of less ice resources.

Floods, droughts and cyclones are the key extreme climatic events in India. The total flood prone area in India is about 40 m ha (12.16% of total land area, Mirza and Ericksen, 1996). Western parts of Rajasthan and the Kutchh region of Gujarat are chronically drought affected. Drought conditions have also been reported in Karnataka, Andhra Pradesh, Orissa and Bihar states (Sharma and Smakhtin, 2004). Drought disasters are more frequent during years following ENSO events. At least half of the severe failures of the Indian monsoon since 1871 have occurred during EI Nino years (Webester et. al., 1998).

Future Climate Scenarios

Increase in atmospheric concentrations of green house gases (GHGs) from anthropogenic activities would warm the earth-atmosphere system. Impact assessment studies of these changes are conducted through numerical experiments performed with coupled atmosphere-ocean global climate modes (AOGCMs, Lal et.al, 2002). Unfortunately, many of the AOGCMs have only a limited ability for realistic portrayal of even large-scale precipitation distribution over Asia/India. However, the Had CM2, ECHA M4, CSIRO, and CCSR/NIES AOGCMs (developed at U.K. Hadley Climate Centre, German Climate Research Centre, Australian Commonwealth Scientific and Industrial Research Organization, and Japanese Centre for Climatic System Research/National Institute for Environmental Studies, respectively) are rated to have some skill in simulating the broad features of present day climate and its variability over Asia/India (Lal and Harasawa, 2000).

Surface Air Temperature: Climate change scenarios that are based on an ensemble of results as inferred from skilled AO GC Ms for Asia and the South Asia sub-region on an annual and seasonal basis are presented in Table 1. The projected area-averaged annual mean warming is 1.6 ± 0.2˚C in 2020s, 3.1± 0.3˚C in 2050s, and 4.6 ± 0.4˚C in the 2080s over land regions of Asia as a result of increase in the atmospheric concentration of GHGs (Lal et.al, 2002). The results suggest that even though aerosol forcing reduces surface warming the magnitude of projected warming is still considerable and could substantially impact the Indian sub-continent. During the summer, an increase in diurnal temperature range is predicted thereby suggesting that the maximum temperature would have a more pronounced increase relative to the minimum temperature (Lal and Harasawa 2001).

Table 1. Plausible changes in area-averaged surface air temperature and precipitation over Asia and South Asia as a result of future increases in greenhouse gases. Numbers in parenthesis are area-averaged changes when direct effects of sulfate aerosols are included.

Regions	**2020s**			**2050s**			**2080s**		
	Temperature change (^oC)								
	Annual	Winter	Summer	Annual	Winter	Summer	Annual	Winter	Summer
Asia	1.58 (1.36)	1.71 (1.52)	1.45 ((1.23)	3.14 (2.49)	3.43 (2.77)	2.87 (2.23)	4.61 (3.78)	5.07 (4.05)	4.23 (3.49)
South Asia	1.36 (1.06)	1.62 (1.19)	1.13 (0.97)	2.69 (1.92)	3.25 (2.08)	2.19 (1.81)	3.84 (2.98)	4.52 (3.25)	3.20 (2.67)
	Precipitation change (%)								
Asia	3.6 (2.3)	5.6 (4.3)	2.4 (1.8)	7.1 (2.9)	10.9 (6.5)	4.1 (1.5)	11.3 (7.0)	18.0 (12.1)	5.5 (3.5)
South Asia	2.9 (1.0)	2.7 (-10.1)	2.5 (2.8	6.8 (-2.4)	-2.1 (-14.8)	6.6 (0.1)	11.0 (-0.1)	5.3 (-11.2)	7.9 (2.5)

(Adapted from Table 11.2 in Lal et.al, 2004)

Precipitation: In general, all AOGCMs simulate an enhanced hydrologic cycle and an increase in annual mean rainfall over most of Asia (Giorgio and Francisco, 2000). An area-averaged annual mean increase in precipitation of 3±1% in the 2020s, 7±2% in the 2050s and 11±3% has been predicted in the 2080s over the land regions of Asia (Table 1). The models show high uncertainty in projections of future winter and summer precipitation over South Asia. The effect of sulfate aerosols on the Indian summer monsoon precipitation is to dampen the strength of the monsoon compared to that seen with GHGs only (Lal et.al, 1995, Roecknor et. al., 1999). Recent observations suggest that there is no appreciable long-term variation in the total number of tropical cyclones observed in the north Indian and South-west Indian Ocean (Lander and Guard, 1998). However, some of the other studies suggest an increase in tropical storm intensities with CO_2 induced warming (Krishnamurti et.al; 1998). Mehel and Washington (1996) indicate that future seasonal precipitation extremes associated with a given ENSO event are likely to be more intense in the tropical Indian Ocean region; anomalously wet areas could become wetter, and anomalously dry areas could become drier during future ENSO events.

High-resolution climate change experiments are better suited to simulate large-scale monsoon circulation over smaller regions. Whereas an increase in rainfall is simulated over the eastern region of India, northwestern deserts see a small decrease in the absolute amount of rainfall in regional climate model (RCM) simulation (Figure 1, Lal et al; 2002). Changes in soil moisture broadly follow those in precipitation except in eastern India, where they decrease as a result of enhanced drainage from soil. Nested RCM simulations have the potential to simulate the onset of the summer monsoon ands its active/break cycle over India.

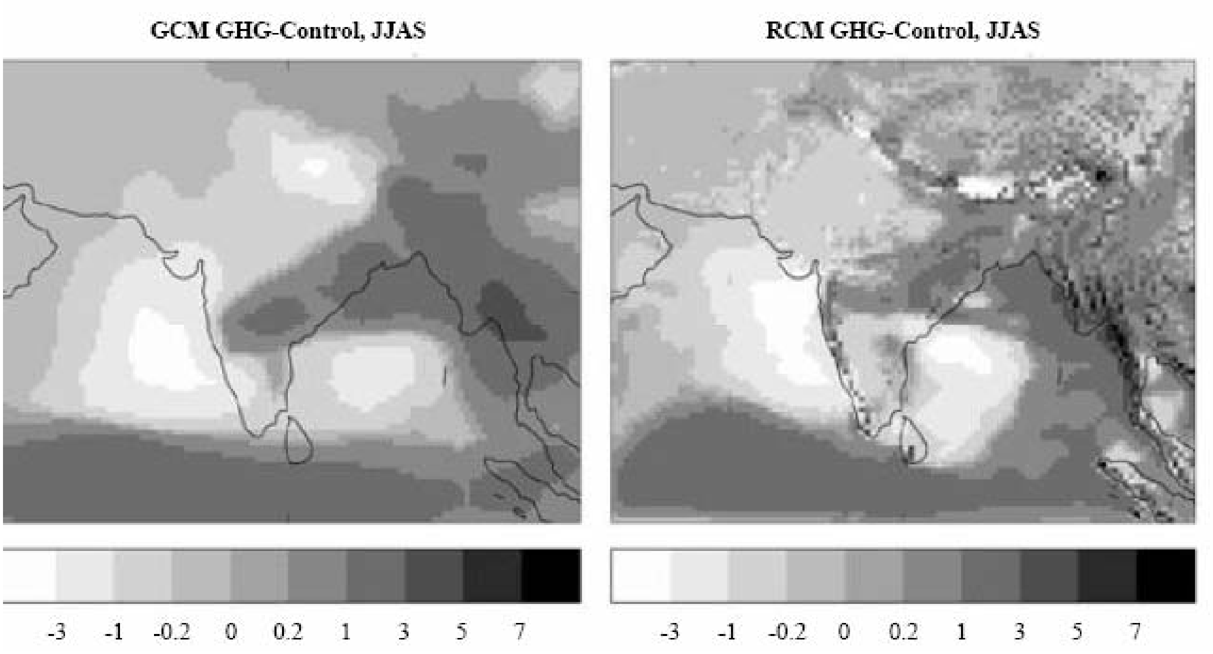


Figure 1. Spatial distribution of changes in monsoon rainfall over the Indian subcontinent as simulated by Hadley Center's global and regional climate models at the time of doubling of CO_2 in the atmosphere. (Source: Lal et al., 2002)

Mountain and Highland Rivers

The Hindukush Himalayan ranges are the source of a number of major Indian rivers. The total amount of water from the Himalayas to the plains of Indian sub-continent is estimated at about 8.6 million m^3/annum. The Himalayas have nearly 1,500 glaciers covering an estimated area of about 33,000 km^2 (Dyurgerov and Meir, 1997). These glaciers provide snow and the glacial melt waters maintain perenniality of the rivers. In the recent decades, almost 67% of the glaciers in the Himalayan ranges have retreated (Yamada et.al; 1996; Fushmi, 2000). Available records suggest that Gangotri glacier is retreating about 30 m yr^{-1}. Further warming is likely to increase melting far more rapidly than accumulation (IPCC, 1998).

While there is a clear evidence of de-glaciation across the whole of the Himalayas, the effect on river flows is likely to be substantially different in different areas (Figure 2, Rees and Collins, 2004). In the eastern Himalayas, high levels of snowfall appear to retard glacial retreat and runoff generated in the non-glaciated areas rapidly lessens the downstream impacts for the Brahamaputra. However, in the western Himalayas the precipitation is lower and the volume of snow at high elevations does not protect the glaciers in the hot summer months. Benchmarking of Himalayan Glaciers for the past three decades has shown that Pindari glaciers are shrinking at a rate of 13 m annually and Gangotri by 30 m. Estimates show that 95% of Himalayan glaciers are shrinking. The short-term danger is floods. In the long term, the rivers may turn into trickles (www.climatehotmap.org) in the summers? Thus the deglaciation is more rapid and the impacts are felt for considerable distance. The Indus is likely to witness large increase in flows for the next half-century, followed by up to 50% reductions from present levels of runoff. In the Ganges, there would be large impacts of de-glaciations in the mountains, but non-glacial forms of runoff in the plains may mitigate the impacts. The IPCC model has predicted a decrease in the number of rainy days (Figure 3).

In summary, the anticipated climate changes will increase the variability of already highly variable rainfall patterns and river flows, requiring greater investments in managing both scarcity and floods.

Impact on Coastal Zone and Marine Ecosystems

Coastal zones are among the world's most diverse and productive environments. With global warming and sea-level rise, many coastal systems will experience increased levels of inundation and storm flooding, accelerated coastal erosion, seawater intrusion into fresh groundwater, encroachment of tidal water into estuaries and river systems and elevated sea-surface and ground temperatures. Related socio-economic impacts can include the loss of property and coastal habitats, increased flood risk and potential loss of life; loss of tourism, recreation and transportation functions and impacts on agriculture and aquaculture through decline in soil and water quality. Particularly at risk are the large delta regions in Asia, where vulnerability was recognized more than a decade ago and continues to increase (Mclean and Tsyban, 2001). A combination of accelerated sea-level rise, increased melting of ground ice, decreased sea-ice cover, and the associated more energetic wave conditions will have severe impacts on coastal landforms, and infrastructure.

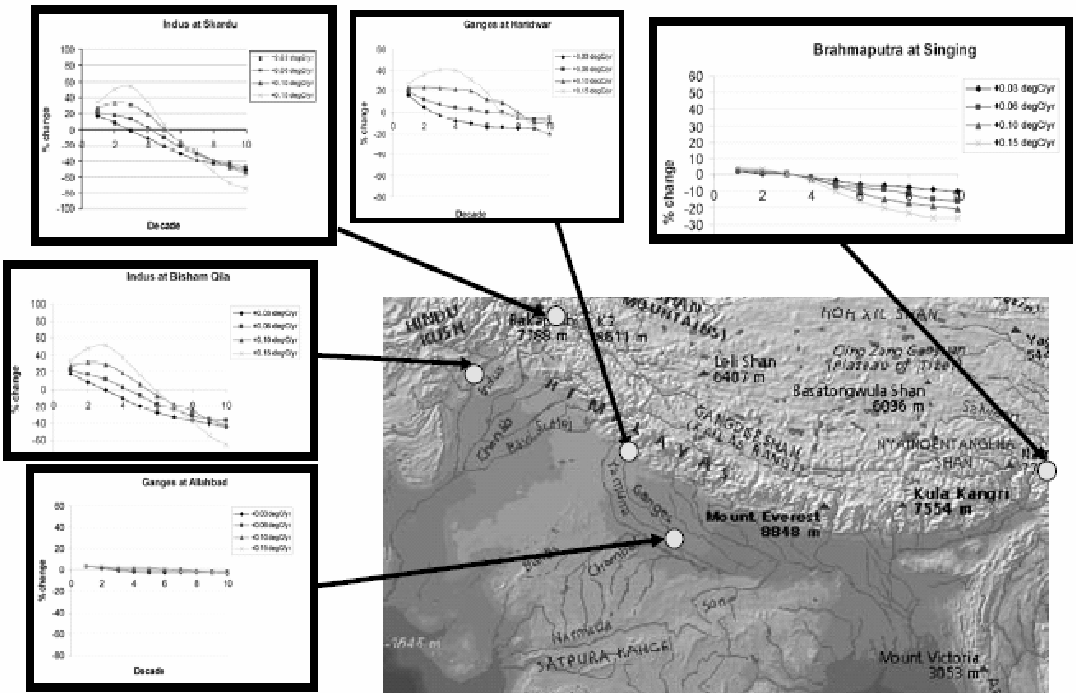


Figure 2. Simulated effects of de-glaciations on Himalayan river flows over ten decades (Gwyn Rees et al., 2005)

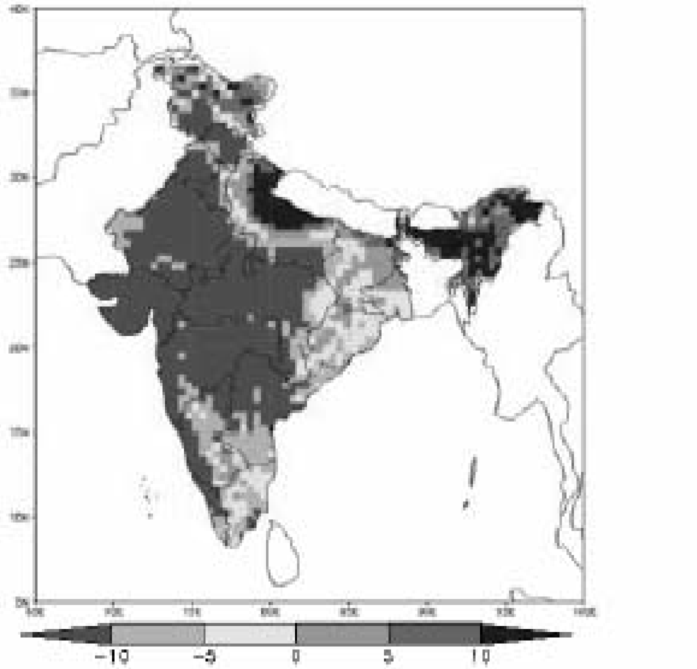
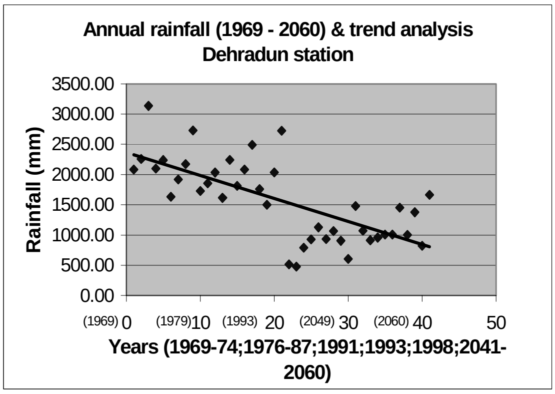
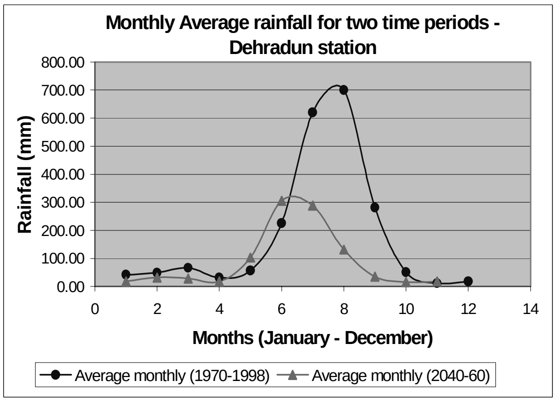


Figure 3. Predicted change in number of rainy days from the 'decreased rainfall' IPCC model.

Case Study: Dehradun Watershed

TERI conducted a modeling study to assess the implications of changes in temperature and precipitation patterns on water availability in the Lakhwar Catchment in the upper Yamuna basin in the Himalayas. In the water shed, 60% of the land area is under forests and 17% area under agriculture (rice, wheat, sugarcane, maize). GROWA and SWAT models were used to assess seasonal water availability in the watershed (present day conditions and in future) thereby predicting changes in seasonal water flows and their spatial distribution. Observed and scenarios data for the precipitation and temperature were used for the period 1969-2060. Annual rainfall and trend analysis showed a substantial decrease in annual and monthly average rainfall for Dehradun station. The decrease in volume of rainfall as well as intensity of rainfall will lead to a decrease in the total availability of water including groundwater recharge. The entire region would experience severe water stress as the monthly flows are going to reduce by at least 20-30%. Annual groundwater recharge presently estimated at 540 million m^3/annum may go down by 30-35% by 2060. Fall in groundwater tables is estimated as 6-8 m on account of climate change and cost of extraction of water would go up by at least 3 to 4 folds by 2060.





This can cause restrictions in the growth of rice and sugarcane, although some of these losses could be offset by the adoption of improved scheduling of irrigation and water conserving practices. Intermittent irrigation for rice, use of straw mulch in sugarcane, and other water saving practices like ridge sowing, alternate furrow irrigation, etc. may prove useful. But for better validation; observed climatic data need to be analyzed for other stations and the impact of change in water resources on agriculture and livelihoods better understood.
,(Source: www.teri.org.in)

India is endowed with a coastline of over 7500 km, 3 of 4 major Indian metropolitans (Mumbai, Chennai and Kolkata) are located in coastal region. Coastal districts covering an area of 379,610 km^2 have an average population density of 455-persons/sq. km. Coastal zones witness higher number of depressions, storms and severe storms each year. Studies under the 'Building and Strengthening Institutional Capacity on Climate Change' (BASIC) project (www.basic-project.net) have shown that though there exists a large variation in extent of vulnerability, there are clusters of districts with low infrastructure and demographic development. As such any occurrence of extreme events (storms, floods, droughts) is likely to be catastrophic in nature. A whopping 942 mm of rain fell on July 26, 2005 in Mumbai, exceeding India's previous all-time, single-day record of 883 mm set in 1912. The heavy monsoon rain triggered deadly floods and led to heavy casualties in coastal areas.

Coastal areas also include complex ecosystems such as coral reefs, mangrove forests, and salt marshes. Many mangrove forests and salt marshes are under stress from excessive exploitation, and salt marshes are under further stress from reclamation. In the Sunderbans (a RAMSAR site) in West Bengal, the rising ocean has flooded about 7,500 hectares of mangrove forests. It is also estimated that with a 1m rise in sea level, Goa may lose 4.3% of its land area, including the inundation of its beaches and tourist spots. Over the past 100 years or so, about 70% of the world's sandy shorelines have been retreating, about 20-30% have been stable, and less than 10% have been advancing. Bird (1993) argues that with global warming and sea-level rise there will be tendencies for currently eroding shorelines to erode further, stable shorelines to begin to erode, and accelerating shorelines to wane or stabilize. Though figures for India are not available, the total expenditure to keep the present level of functions and stability for about 1,000 Japanese ports is estimated to be USD 110 billion for a 1-m sea level rise (Mimura et.al, 1998).

Preparedness and Adaptation to Climate Change

Climate induced disasters can have devastating effects on the economy, cause huge human losses and can significantly set back development efforts of a region or a state. There has been a disturbing increase in the number and severity of such natural disasters. Those living in developing countries and especially those with limited resources tend to be more adversely affected. As a number of the most vulnerable regions are in India, preparedness and adaptation to disasters has emerged as a high priority for the country.

Many parts of the Indian sub-continent are susceptible to different types of disasters owing to the unique topographic and climatic characteristics. About 40 million ha of land mass is vulnerable to floods (12.16% of total land mass), while 68 percent of the net sown area is vulnerable to drought. Data resented in Table 1 and Table 2 emphasize the point that natural disasters cause major set backs to development and it is often the poorest and the weakest that are most vulnerable to such events. Given the high frequency with which one or the other part of the country suffers due to disasters (compounded by climate change), mitigating the impact of disasters must be an integral part of India's development planning.

Table 1. Flood damage in India during 1953-2004

Item	Average	Maximum (year)
Area affected (m ha)	7.63	17.50 (1978)
Crop area affected (m ha)	3.56	10.15 (1988)
Population affected (million)	32.92	70.45 (1978)
Human lives lost (No.)	1,590	11,316 (1978)
Cattle lost (No.)	94,485	618,248 (1979)

Houses damaged (No.)	1,234,616	3,507,542(1978)
Total damage (Rs. Million) *	18,052	88,645 (2000)

1* USD = Rs.45/-

Table 2. Severe droughts in India during last 100 years

Year	% Country area affected	% of deficit rainfall over entire India	% of deficit rainfall over drought region
1918	71	-26	-49
1965	41	-17	-36
1972	47	-25	-35
1979	45	-21	-38
1987	50	-18	-45

Institutional Arrangements

The subject of disaster management is not specifically mentioned in the Indian constitution. Similarly, there is no enactment either of the central or any state government to deal with management of natural/ man made disasters. However, the country has integrated the relevant administrative machinery and the basic responsibility for undertaking rescue, relief and rehabilitation measures in the event of natural disasters into that of the concerned state government (http://planningcommission.nic.in/reports). The central government supplements the efforts of the states by providing financial and logistic support. The Central Government Ministry of Home Affairs is the nodal ministry for coordination of relief and response, and overall natural disaster management, and the Department of Agriculture and Cooperation is the nodal ministry for drought management. Other decision making bodies include (i) the Natural Crisis Management Centre (NCMC) chaired by the Cabinet Secretary (ii) the Crisis Management Group (CMG) chaired by the Central Relief Commissioner, and (iii) technical organization such as Indian Meteorological Department (cyclone, drought, heat/cold waves), Central Water Commission (river flows, dams, floods, glaciers). Furthermore, the establishment of a National Disaster Management Authority (NDMA) is being contemplated as the apex structure within the government for the purpose. The district administration is the focal point for implementation of all government plans and activities. The Indian Armed Forces are supposed to be called upon and to take on specific tasks only when the situation is beyond the capability of the civil administration. The Government of India also has linkages with the UN Office for Coordination of Humanitarian Affairs (UNOCHA), the United Nations Development Program (UNDP) and the UN Disaster Assessment and Coordination System (UNDAC) for leveraging external/ international assistance and expertise. These agencies help in making good estimates of the losses during major disasters, solicit aid from international donors and coordinate with the concerned national agencies in effective and quick mediation of the disasters.

Preparedness and adaptation for some of the specific climate induced phenomenon is discussed below.

(i) Advance Warming and Prevention of Floods

Recent estimates by the Planning Commission show 45.65 million ha of land within the Ganga, Brahamaputra and Mahanadi river basins as flood prone. Floods are likely to further intensify in Brahamaputra and Ganga basin due to enhanced deglaciation and snow melt discussed above. Planning for flood management in India started after the devastating floods in 1954 with the establishment of the National Flood Commission (*Rashtriya Barh Ayog*). The major emphasis has been on structural measures and an estimated area of 16.45 million ha has benefited through construction of 34,398 km of embankments; enlargement of capacity and straightening of 51,318 km of drainage channels; 2400 town protection works; and the relocation of 4721 villages onto raised lands (CWC, 2004). The major non-structural measures have included (a) flood forecasting and warming (b) flood plain zoning (c) flood proofing (d) disaster preparedness and response planning and (e) flood relief. With the establishment of first flood forecasting station in the Yamuna River in the capital in 1958, the total number of forecasting stations has now grown to 173. Flood forecasts are disseminated to the different agencies through all possible communication means for the benefit of the likely flood affected population. Daily flood bulletins are also hosted on the website: www.india-water.com for quick disseminations. The information is comprehensive and reasonably accurate (± 15 cm) with suitable advisories. On an average, 6000 forecasts at various places in the country are issued during the monsoon season every year. Suitable arrangements have also been put in place for sharing the river flow data of the international rivers passing through the neighboring countries of Nepal, Bhutan, Bangladesh and Myanmar.

The flood forecasting system in the country has evolved over the past five decades and appears to be reasonably good for forewarning the potentially affected populations and regions. But this relates mainly to flood levels in the major rivers and gives no information about the extent of the areas likely to be affected and the corresponding mitigation strategy. Moreover, all the potentially flood affected areas have high population densities of resource poor people. Despite massive investments in construction of flood protection structures, vast populations are annually affected by floods and the country does not seem to be well prepared to protect itself against climatic change induced more frequent floods of higher intensities.

(ii) Management of Droughts

Based on the rainfall deficiency for the last 100 years, on average 19% of the area and 12% of the population is annually affected by droughts in the north-western and southern states of the country. The primary impacts are reduced water availability for domestic, agriculture and livestock; low to failed agriculture production and reduced hydropower generation. This leads to reduced incomes for the people dependent on farming and livestock, dwindling fodder stocks, decline in nutrition and health status and increased incidences of debt. It also has impacts on the wider economy with the reduced availability of agricultural produce and constraints on power production.

Government schemes to combat droughts include the Desert Development Program (DDP), the Drought Prone Areas Program (DPAP), the Integrated Watershed Development Program (IWDP) and the National Watershed Development Program for Rainfed Areas (NWDPRA). These are area based development programs where certain structural measures like stabilization of sand dunes, regeneration of pasture lands, maintenance of traditional water resources and afforestation with region specific species is undertaken. Specific research institutes have been devoted to the development of germplasm, technologies, practices and policies for better adaptation to droughts. Traditional coping strategies in response to drought include migration of human and livestock population to safer areas, sale of assets, dependence on government relief works, and water and food aid, sharing and cooperation, diversification in sources of income and borrowing from banks and money lenders. State government also makes arrangements for supply of drinking water to the affected populations through water tankers and special water trains. NGOs play an important role through supplies and management for alleviating the drought impacts in remote and inaccessible habitats. Water harvesting at individual, community and state level has emerged as a strategic tool for effectively mitigating the droughts and improving productivity and livelihoods (Sharma, 2004). Even in drought affected areas some storms generate considerable runoffs which when harvested in underground cisterns (drinking water for human/ cattle population), village ponds (cattle and domestic needs) and runoff-based farming systems can help the communities to be well prepared to face droughts of different intensities. However, such interventions are not universally applicable, especially where prolonged droughts are expected.

The past efforts in drought management at the central and state government level have ensured that droughts do not trigger wide spread food famines and epidemics. Medium and long range weather forecasts, creation of food and fodder depots, providing employment and relief to the affected families, building resilience into traditional agricultural system appear to be good steps in combating low /medium intensity droughts. But most of the responses and institutional mechanism are at best ‘ad-hoc drought/ famine relief works for managing an event when it strikes’ rather than measures for drought preparedness, drought management and drought proofing of the vast areas which might be impacted as a result of climate change.

(iii) Adaptation of Indian Agriculture

Agriculture and allied activities constitute the single largest component of India’s economy, contributing nearly 25% of GDP and supporting about 67% of the rural population. However, given that 60% of the cropped area is still dependent on rainfall, Indian agriculture continues to be fundamentally dependent on the weather. Climate variability and change, along with population growth and increased demands from a growing economy, will seriously endanger sustained agricultural production in India in the coming decades. Although wheat crops are likely to be sensitive to an increase in maximum temperature, rice crops would be vulnerable to an increase in minimum temperature. The adverse impacts of likely water shortage on wheat productivity in India could be minimized to a certain extent under elevated CO_2 levels; these impacts, would be largely maintained for rice crops, resulting in a net decline in rice yields (Agarwal and Sinha, 1993; Rao and Sinha, 1994; Lal et. al., 1998). Acute water shortage adversely affects wheat, and more severely, rice productivity in India even under the positive effects of elevated CO_2 in future. The country has refocused its research programs in the areas of biotechnology to formulate suitable gene constructs, which may be able to impart drought resistance and heat and cold tolerance to the major crops. Crop production techniques are also being continuously improved to enhance input use efficiency, conserve the resources and attain higher yields. However, effective dissemination and uptake of the new knowledge by millions of small and resource poor farmers remains a major challenge. Major initiatives like interlinking of rivers basins is likely to insulate large areas from the vagaries of droughts and floods and provide long term solutions to better tackle the natural disasters.

Recommendations

Adaptation to climate change has the potential to substantially reduce many of the adverse impacts of climate change and enhance beneficial impacts. The key features of climate change vulnerability and adaptation are those related to variability and extremes, not specifically changed average conditions. Developing countries like India with limited economic resources, poor infrastructure; insufficient levels of technology, information and skills; traditional and non-responsive bureaucratic institutions coupled with inequitable empowerment and access to resources have inadequate capacity to adapt and are highly vulnerable. Enhancement of adaptive capacity is a necessary condition for reducing vulnerability to climate induced changes in availability of water resources, frequency and intensity of extreme events like floods, droughts, heat and cold waves, fragile coastal ecosystems and the associated impacts on agriculture and other livelihood options. For a comprehensive, integrated and futuristic policy framework on adaptation to climate change in water resources the following recommendations need to be seriously considered.

1. Improving Institutional Capacity

There is a pressing need for improvement and strengthening of existing institutional arrangements and systems to make the initial response to a disaster more effective and professional. Some of the areas where improvement is urgently needed are:

i. Integrated planning for extreme climatic events/ disasters at all levels from district to state and central government. This also needs to include the relevant communities and civil society organizations.

ii. Establishment of a national standby, quick reaction team, which can provide an experienced response at the affected location in the country.

iii. Media policy geared to handling the growing phenomenon of real time television reporting, which generates enormous political pressure on a government to respond quickly and effectively.

iv. Modern unified legislation for disaster management with clear definitions of what constitutes a disaster/ extreme event at national/ state/ local level. Provisions of the legislation may be implemented through the setting up of a modern, efficient and powerful 'Disaster Management and Coordination Authority'.

v. Provision of adequate financial support to the on-going/ new centrally sponsored development schemes, which enhance the adaptation and reduce disaster vulnerability of the communities. Even the High Powered Committee of the national Planning Commission has advised that 10 per cent of the plan funds at the national, state and district levels be used for schemes which specifically address prevention, reduction, preparedness and mitigation of extreme events (no regret measures). However, this provision is still advisory in nature and needs to be made mandatory while making state wise allocations of the central grants.

vi. Build a comprehensive, robust and accessible database of the land use, demography and infrastructure along with current information on climate, weather, water resource structures etc. for accurate planning, warning and assessment of impacts. Much of the necessary data already exists, but either because of security concerns or institutional constraints is not readily available.

vii. Establish a National Network of all knowledge- based institutions which research and share community of best practices with extreme event managers, decision makers, communities and all other stakeholders.

viii. Insurance can be a powerful tool for reducing vulnerability to climate change by transferring or sharing risk. Weather-indexed insurance can help farmers protect their overall income rather than yield of a specific crop and reduce overall vulnerability to climate variability and change.

2. Development and Management of Water Resources

Water managers have experience adapting to change. Adaptations can involve management on the supply side (e.g., altering infrastructure or institutional arrangements) and on the demand side (changing demand or risk reduction). The following no-regret policies shall generate net social benefits regardless of climate change.

i. Enhance water storage capacity: Per capita dam storage capacity in India is one of the lowest in the world (200 m^3/capita as compared to 5000 m^3 in the USA, 1000 m^3 in China, and around 900 m^3 in South Africa) and needs to be substantially enhanced to offset the seasonal and long term resource availability fluctuations and make efficient use of the available resources.

ii. Capture the glacial and snowmelts: It has been predicted that global warming in the tropics shall cause enhanced de-glaciations and snowmelts during the next 7 to 8 decades in the northern Himalayas. This calls for effective capture of these additional resources to tide over the subsequent reduced supplies and mitigate the impact of flash floods.

iii. Inter-basin transfers of some form are most likely inevitable. The Government of India has already developed a National Integrated Water Development Plan and National River Linking Project. This call for the transfer of water from relatively water rich eastern (and possibly northern) Himalayan rivers to the deficit southern basins. This shall require substantial financial commitments and acceptable negotiations with the neighboring countries (Nepal, Bangladesh). At least portions of this project are likely to be implemented, but requires a comprehensive strategic analysis of the available options and concerns raised by environment and social groups.

iv. Mitigation measures on individual structures can be achieved through improved design standards and performance specifications. In order to save larger outlays on rehabilitation and reconstruction subsequently, a mechanism would need to be worked out for allowing components that specifically help projects developed in disaster prone areas withstand the impact of the large variations/natural disasters (land slides, flash floods, flow blockages etc.).

v. Enhance water productivity at all levels through field, farm, and command area and basin level improvements. Multiple uses of water, ensuring hydrological sustainability of intensive cropping systems, reducing non-beneficial evaporation losses, breeding drought/ flood tolerant and water efficient cultivars and community participation in resource management shall help in demand management of the resources.

vi. Initiate effective steps for private partnership in distribution and management of water systems at all levels for irrigation, and domestic and industrial supplies. Price of water supplies must indicate its scarcity value and subsidies (if any) should be targeted to the vulnerable sections of the society.

3. Adaptation to Floods

The traditional flood control and flood management methods already in place in the country need to be streamlined, modernized and made effective to take care of more frequent, intense and potentially unprecedented floods inundating vast land areas. More specifically, the following steps shall be useful:

i. In the vast low lying areas in the east people have to live with floods and learn better techniques to minimize losses with more reliance on non-structural measures. Integrated farming systems with suitable blend of aquaculture and agriculture can provide better livelihood means for the vulnerable communities, and if appropriately designed, can be more resilient to extreme events. This can be achieved through demonstrations of successful models, capacity building of extension staff and communities and allocation of adequate funds.

ii. Existing flood forecasting using computer may refine methodology based on comprehensive catchments modeling using real time and remotely sensed data and GIS. The present lead-time of 12 hours to 72 hours needs to be enhanced for better preparedness and evacuation/ relief operations.

iii. The water level forecast (which makes little sense to the user agencies) need to be converted into potential area inundation forecast so that relief and rehabilitation response is better targeted.

iv. Updating and digitization of flood plain zoning maps and better enforcement of flood plain zoning regulations shall considerably mitigate the flood impacts.

v. Encourage community participation in flood management, as they will have better knowledge of local needs and potential and building quick resilience. This shall require setting up of a community oriented and empowered institutional framework backed by strong capacity building measures.

4. Prevention and Management of Droughts

Drought management in India, despite being efficient and proactive, is still an ad-hoc and empirical famine intervention for providing instant relief to prevent starvation (Samra, 2004). The concept of an institutionalized process of management consisting of vulnerability mapping, community involvement, prevention, mitigation, quick responses, a comprehensive relief mechanism, use of modern tools and procedures of monitoring, impact documentation and capacity building is not yet fully in place in India. The following no-regret measures shall be helpful in better management and mitigation of droughts:

i. The existing traditional, time consuming and bureaucratic system of drought declaration and management may be replaced with a comprehensive, objective but decentralized or community empowered institutionalized system of drought declaration and management.

ii. Detailed vulnerability maps of droughts based on long-term trends and real time data are essential for developing strategic management plans.

iii. Prevention, mitigation, preparedness, institutional infrastructures, capacity building and logistic of relief material for a quick response should be planned and located according to vulnerability level of the region.

iv. Decision support systems for estimating losses of crops, orchards, trees, grasslands, and livestock; and surface and groundwater resources may be calibrated for different vulnerable regions and livelihood opportunities.

v. Crop- centered management policy should shift in favor of robust and integrated livestock, trees, agro-forestry and grassland based livelihood opportunities along with promotion of off-farm income generation skills.

vi. Water harvesting at local, community and regional level should be considered as a long-term strategic intervention for mediating the drought impacts.

References

Amarasinghe, U., B.R.Sharma, N. Aloysius, C A Scott, V.U. Smakhtin and C de Fraiture. 2005.IWMI Research Report 83, International Water Management Institute, Colombo, Sri Lanka.37 pp.

Bandyopadhaya,J.1995**.** Water management in the Ganges-Brahmaputra basin: emerging challenges for the 21st century. Water Resources Development 11(4): 411-442.

Bird, E.C.F.1993. Submerging Coasts: The Effect of a Rising Sea Level on Coastal Environments. John Wiley and Sons, Chicster, UK, 184 pp.

C.W.C.2004. Water and Related Statistics-May 2004. Central Water Commission, New Delhi, India.

Dyurgerov, M. and M. Meier. 1997. Mass balance of mountain and subpolar glaciers: a new global assessment for 1961- 1990. Arctic and Alpine Research, 29, 379-391.

Giorgi, F. and R. Francisco.2000.Evaluating uncertainties in the prediction of regional climate.Geophysical Research Letters, 27(9), 1295-1298.

Gwyn Rees and Davis Collins.2004. An assessment of the potential impacts of de-glaciations on the water resources of the Himalayas, Draft report, HR Wallingford, UK, as cited in ‘ India’s Water Economy: Bracing for a Turbulent Future’, The World Bank, New Delhi, India

IPCC.1998. The Regional Impacts of Climate Change: An Assessment of Vulnerability: Special Report of IPCC Working Group II (Watson, R.T., M.C. Zinyowera, and R.H.Moss (eds.). Inter-governmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 517 pp.

Karl, T.R., R.W. Knight, and N.Plummer. 1995. Trends in high frequency climate variability in the twentieth century. Nature, 377, 217-220.

Kriplani, R.H., S.R.Inamdar and N.A. Sontake.1996. Rainfall variability over Bangladesh and Nepal: comparison and connection with features over India. International Journal of Climatology,16, 689-703.

Krishnamurti, T.N., R. Correa-Torres, M.Latif. and G. Daughenbaugh. 1998. The impact of current and possibly future SST anamolies on the frequencies of Atlantic hurricanes, Tellus, 50A, 186-210.

Lal, M.and H.Harasawa.2001. Future climate change scenariosfor asia as inferred from selected coupled atmospheric-ocean global climate models. Journal of Meteorological Society of Japan, 79(1), 219-227.

Lal, M. and H. Harasawa.2000. Comparison of the present day climate simulation over Asia in selected coupled atmospheric-ocean global climate models. Journal of Meteorological Society of Japan, 79(1), 871-879.

Lal, Murari; H. Harasawa and D. Murdiyarso. 2002. Asia. In: Climate Change 2001: Impacts, Adaptation and Vulnerability (James J McCarthy, O.W. Canziani, N.A. Leary, D.J.Dokken and K.S.White , Eds.). Cambridge University Press, UK.pp.535-581.

Lal, M., U, Cubaasch, R. Voss and J. Waszkewitz.1995. Effect of transient increase in greenhouse gases and sulphate aerosols on monsoon climate. Current Science, 69(9), 752-763.

Lander, M.A. and C.P.Guard. 1998. A look at global tropical cyclone activity during 1995: contrasting high Atlantic activity with low activity in other basins. Monthly Weather Review, 122, 636-651.

McLean, R.F.and A.Tsyban. 2004. Coastal zones and marine ecosystem. In: Climate Change 2001: Impacts, Adaptation and Vulnerability (James J McCarthy, O.W. Canziani, N.A. Leary, D.J.Dokken and K.S.White , Eds.). Cambridge University Press, UK.pp 345-372.

Mehel, G.A., and W.M.Washington.1996. El Nino-like climate change in a model with increased atmospheric CO2 concentrations. Nature, 382, 56-60.

Mimura, N., J.Tsutsui, T.Ichinose., H.kato, and K.sakai.1998. Impacts on infrastructure and socio-economic system In: Proceedngs of Coastal Dynamics' 95, Gdansk, Poland, September 4-8, 1995, American society of Civil engineers, Reston, VA, USA, pp 607-616.

Mirza, M.Q. and N.J. Erickson.1996. Impact of water control projects on fisheries resources in Bangladesh. Environmental Management, 20(4), 527-539.

Rai, S.C.1999. Land use change and hydrology of a Himalayan watershed. In: Abstract Book of the 1999 IGES Open Meeting of the Human Dimensions of Global Environmental Change Research Community, Shonan Villge, Japan, 24-26 June, 200 pp.

Rockner, E., L. Bengtsson, J.Lelieveld, and H.Rodhe. 1999. Transient climate change with a coupled atmospheric-ocean CCM, including the tropospheric sulphur cycle, Journal of Climate, 12, 3004-3032.

Rupakumar, K., K. Krishnakumar and G.B.Pant.1994. Diurnal asymmetry of surface temperature trends over India. Geophysical Research Letters, 21, 677-680.

Samra, J.S. 2004. Review and analysis of drought monitoring, declaration and impact management in India. IWMI Working Paper 84, Drought Series Paper 2, International Water Management Institute, Colombo, Sri Lanka.

Sharma, B.R. and V.U. Smakhtin. 2004. Water harvesting as a strategic tool for drought mitigation in Southwest Asia. Proceedings of 55th International Meeting of the International Commission on Irrigation and Drainage, FAO/ ICID International Workshop on Water Harvesting and Sustainable Agriculture, Moscow, Russia. September 2004.

Sharma, B.R., C.A.Scott and T.Shah.2004. Groundwater-Energy Nexus: Implications for Sustainable Resource Use. Groundwater Use in Northwest India-Workshop Papers (Abrol, I.P., B.R.Sharma and G.S.Sekhon, Eds), Centre for Advancement of Sustainable Agriculture, New Delhi, India. pp 119-129.

Singh, N. and N.A. Sontake. 2001. Natural and anthropogenic environmental changes of the Indo-Gangetic Plains, India. Climatic Change (Communicated).

TERI.2005. Impact of climate change on water resources. IFS Training Program-2005. The Energy and Resources Institute, India Habitat Center, New Delhi, India (www.teri.org.in)

The World Bank. 2005. India's Water Economy: Bracing for a Turbulent Future. Draft report. The World Bank, New Delhi, India.

Webster, P.J., V.O.Magana, T.N.Palmer, J.Shukla, R.A.Thomas, M.Yanagi. and T.Yasunari.1998. Monsoons: Processes, Predictability and the prospects of prediction. Journal of Geophysical Research, 103 (C7), 14451-14510.

Yamada, T., H.Fushimi., R.Aryal., T. Kadota., K. Fujita., K.Seko. and T.Yasunari.1996. Report avalanches accident at Pangka, Khumbu Region, Nepal in 1996. Japanese Society of Snow and Ice, 58(2), 145-155.