Sustainable water management in India considering likely climate and other changes

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With growing scarcity of water and deteriorating quality, water resources management in India is becoming more challenging with the passage of time. This article discusses the likely impacts in the water sector and the overarching actions that India need to initiate to overcome/manage them.

Keywords: Climate change, impacts, sustainable water management, water scarcity.

WATER is a finite but widely present resource. It is a good solvent, which makes it highly vulnerable to pollution. Despite its wide presence, water availability and demand at many places have high degrees of mismatch: spatial and temporal. Many a times, it is a challenge to provide water of desired quantity and quality at a desired place. This is especially true for monsoon climates where 70–90% of the annual rain falls in just 3–4 months. This leads to too much water and often floods in the wet season, and too little water and often droughts in the dry season. At times, enough water may be available but the quality may be so poor that it is of no use without treatment.

Sustainable water management in India poses numerous challenges: bridging the increasing gap between demand and supply, providing enough water for production of food, balancing the uses between competing demands, meeting the growing demands of big cities, treatment of wastewater, sharing of water with the neighbouring countries and among the co-basin states, etc.

Each day, a person drinks 2–4 litres of water and uses 10–15 litres for other essential needs. Clearly, meeting the basic water needs is a governance problem. Globally only about 14% of all water use is for domestic needs (drinking, cooking, washing, etc.). Each day, a typical individual consumes food that requires 2000–5000 litres of water to produce. Hence, producing food for an additional 40 crore people in India, which may be added in next 40 years (the current population is 121 crores), will be a big challenge and calls for fundamental technological and management changes in the way we have been managing our natural resources.

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Climate change

Intergovernmental Panel on Climate Change (IPCC) defines climate change as a change in the state of the climate that can be identified by changes in the mean and (or) the variability of its properties and that persists for an extended period, typically decades or longer. Such changes may be due to natural internal processes or external forcings, or due to persistent anthropogenic-induced changes in the composition of the atmosphere or in land use/land cover.

At times, there are questions whether climate change is real or just a hype. Working Group 2 of IPCC[1] notes that 'Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.' Instrumental observations and reconstruction of the temperature data have shown that there has been a significant increase in the temperature during the past 100 years. Thus climate change is for real and is not just a product of imagination.

Climate may change due to numerous reasons. These include changes in the concentrations of greenhouse gases (GHGs), aerosols, volcanic activity, Milankovitch cycles and solar radiation. Three important GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). While GHGs are emitted due to natural as well as human actions, anthropogenic actions (e.g. burning of fossil fuels, agriculture and land-use/land-cover changes) are the major reasons for their higher emission over the past few decades. According to IPCC[2], no driver other than GHGs provides a scientifically sound explanation of most of the warming observed over the past few decades.

There is considerable variation in emission of GHGs by different countries. An estimate of GHG emissions in India for 2007 (Table 1) has been provided by the Ministry of Environment and Forests (MoEF)[3]. Between 1994 and 2007, some of the sectors indicate significant growth in GHG emissions such as cement production (6.0%), electricity generation (5.6%) and transport (4.5%) (ref. 3).

Table 1. Green house gas (GHG) emissions for India by sectors for 1994 and 2007 in million tonnes of CO_2 equivalent (MTCeq)

Sector	Emissions in 1994		Emissions in 2007		
	MTCeq	In (%)	MTCeq	In (%)	CAGR (%)
Electricity	355.03	28.4	719.30	37.8	5.6
Transport	80.28	6.4	142.04	7.5	4.5
Residential	78.89	6.3	137.84	7.2	4.4
Other energies	78.93	6.3	100.87	5.3	1.9
Cement	60.87	4.9	129.92	6.8	6.0
Iron and steel	90.53	7.2	117.32	6.2	2.0
Other industries	125.41	10.0	165.31	8.7	2.2
Agriculture	344.48	27.6	334.41	17.6	–0.2
Waste	23.23	1.9	57.73	3.0	7.3
Total without LULUCF	1251.95		1904.73		3.3
LULUCF	14.29		–177.03		
Total with LULUCF	1228.54		1727.71		2.9

Percentage emissions from each sector are with respect to total GHG emissions without LULUCF in 1994 and 2007 respectively. (Source: ref. 3).
LULUCF, Land use land use change and forestry; CAGR, Compound annual growth rate.

For India, GHG emissions from the energy, industry, agriculture and waste sectors constituted 58%, 22%, 17% and 3% of the net CO_2 equivalent emissions respectively. LULUCF sector in India was a net sink which sequestered 177.03 million tonnes of CO_2 equivalent (MTCeq) per capita emission for India is 1.57 TCeq/yr. Compared to this, emissions for USA stand at 19.1, United Arab Emirates 29.91, UK 8.6, Germany 9.71 and China 4.57 TCeq/yr (source: http://www.carbonplanet.com/country_emissions). Obviously there is considerable inequality in the emissions across the countries. At the same time, there will be large inequality in the impacts of climate change. Rich countries consume more resources, but due to their infrastructural and financial strengths, the adverse impacts felt are less. Poor countries consume lesser resources, but their infrastructure and financial conditions are precarious and, therefore, the people have to bear the higher brunt of adverse impacts.

Developed countries are generally less vulnerable to the adverse impacts of climate change than the underdeveloped ones, even where impacts are potentially serious. Large parts of The Netherlands are located below the level of the surrounding sea, and it depends on engineering structures such as dikes and sluices for safety. However, the Dutch have the technology and financial resources to cope with the threats due to expected rise in sea levels. On the other hand, another low-lying country Bangladesh, has limited capacity to address the threats due to sea-level rise and thus the people of Bangladesh are more vulnerable compared to the Dutch. Sea level along the Indian coast has been rising at the rate of 1.06–1.25 mm/yr (ref. 3). By 2100, there may be about 50 cm rise in sea level, which directly translates to displacement threat to large number of the people living along the 7517 km long coastline.

According to the IPCC Chairman, 'Very soon, climate change impacts will exceed the capacities of local communities. And remember, poorest countries, and the poorest communities in these countries are the most vulnerable to these effects.' Due to a large range of topographic, climatic and demographic conditions, and limited resources to counter the adverse impacts of climate change, India is highly vulnerable to it. This article attempts to examine the challenges that water managers in India are likely to face due to the combined impacts of population rise, socio-economic growth and climate change, and the actions that are needed to meet them.

Climate change and the water sector

Although many climatic components impact water resources, the two most crucial variables are temperature and precipitation. Global warming is expected to accelerate the hydrological cycle, which is a thermally driven system. Warming temperatures will also mean that more precipitation will fall as rain and less as snow. This will mean reduction of glacier size and depleting snow/glacier melts in the long run. In the regions where appreciable river flows come from snow/glacier melts, there might be changes in the mechanism of run-off production and its timing. Rising temperature may also increase potential evapotranspiration from crops/vegetation and land surfaces, and higher water demands from the population (of course, it depends upon other related conditions such as humidity, wind velocity, etc.). In some basins, evapotranspiration has been found to be decreasing and this is termed as the evapotranspiration paradox[5].

Global warming is also likely to accelerate extreme events: floods, droughts and rain storms. The precipitation pattern is likely to change in two ways: (i) the temporal patterns or the monthly distribution of annual precipitation may change and (ii) the spatial pattern may change: some areas receiving high precipitation will receive less and vice-versa. This change is termed by some experts as 'wet getting wetter' and 'dry getting drier'. In the coastal areas these effects are compounded by the sea-level rise. The three types of impacts are different, and call for different responses in terms of adaptation, but they are also strongly inter-related.

Trend analysis of past precipitation data in India has not shown any major widespread change in the patterns so far[6] but the results of General Circulation Models (GCMs) show that in future these patterns are likely to change[2]. These changes could be in the seasonal patterns as well as the quantity of precipitation; some areas are likely to receive more precipitation, and others less. Intensity of precipitation may also change.

A number of processes are involved in run-off production in a catchment. Most of these processes occur concurrently and interactively[7]. Climate (and land use/land cover and demographic) change adds complexity to these interactions. In some cases, a combination of these impacts on water resources may exacerbate the existing problems; in other cases, it is possible that the adverse impacts on water resources may diminish. For example, the ageing and poorly maintained embankments, combined with the growth of residential, commercial and industrial development in the flood plains has substantially increased flood risk in the adjacent areas (recall the flooding in Bihar due to the breach in Kosi embankment in 2008 and the flooding of habitats constructed in the flood plains of Tapi river in Surat). In some locations, climate impacts will exacerbate this problem due to increased precipitation intensity, higher peak run-off, or changes in the form of precipitation that increase run-off. Due to these changes, incidence of floods and droughts will increase[1]. Managers of hydro-structures have to face many challenges and climate change will introduce one more complexity in the decision making process.

Potential climate change impacts affecting water availability include changes in precipitation amount, intensity, timing[1,2] and form (rain or snow); changes in snowmelt timing; and changes to evapotranspiration. In India, winter precipitation is projected to decline[8] and this is likely to lead to higher need for rabi irrigation, lesser storage and increased water stress during the pre-monsoon months. Intensity of rains is projected to increase, which will imply more frequent and severe floods and lesser recharge to groundwater. As more areas and hence more population will fall under severe water stress, this will be the most pressing water management task in the near future. Shen[9] noted that climate change will have a significant impact on China, especially in the north. In the next 50–100 years, an average increase in precipitation is not likely to alleviate water shortage in North China. Further, due to rise in sea-water level, cities in the coastal areas will be at increased risk and the delta areas may face more flooding.

Impacts on water-related sectors

A brief summary of the water-related sectors which will be impacted by climate change is given here. Obviously the impacts will be different depending upon the country and the existing climatic and socio-economic conditions. A detailed discussion on the related issues has been given in the Fourth Assessment report and related documents by IPCC[1]; numerous other publications discuss related topics. Reports produced by international organizations such as the World Bank, UNESCO, the World Water Assessment Programme, The National Action Plan on Climate Change of the Government of India (2008), MoEF, Government of India and others provide useful insight on climate-change impacts on water resources.

According to the United Nations, globally, nearly 70% of all water consumption is by the agriculture sector, nearly 22% is used by the industries and 8% is for domestic use (http://www.unwater.org/statistics_use.html). A review of current water use in the world shows that the global water use has tripled over the last 50 years, and it is likely that almost 50% of the world's population will be living under water stress by 2030 in a 'business as usual' scenario.

Water demand for irrigation will depend upon the combined impact of increased temperatures, higher humidity, wind and changes in sunshine hours. However, more efficient water use by vegetation as a result of higher CO_2 concentration may reduce this impact. Some areas may also experience an increased growing season, which could increase demand. Water requirement for thermal energy generation could increase, depending on future trends in water-use efficiency and the construction of new plants.

A major boost to agricultural production, and also to productivity of water in agriculture (more crop per drop) was achieved with the green revolution in the 1960s. However, more than 20% of our food production is unsustainable since it depends on over-pumping of finite groundwater resources[10]. According to the Central Ground Water Board (CGWB)[11], the number of over-exploited groundwater blocks in the country rose to 839 in March 2004. This number was 253 in 1984–85, 383 in 1992–93 and 445 in 1997–98 (ref. 12). Further, the stage of groundwater development was 37% in 1998 (ref. 12), which rose to 58% in 2004 (ref. 11). Groundwater mining is harmful in many ways: reduced baseflow in the rivers, release of geogenic pollutants such as arsenic, wells going dry and higher energy requirement of water extraction, etc. Hence, another crop productivity revolution with respect to water is required. Many developing countries have rice productivity of about 1 tonne/ha; countries with better technology and water management produce about 5 tonne/ha by consuming nearly the same water. Obviously, there is considerable scope for improving water productivity in India.

Hydropower projects may be classified in two major types: run-of-river (ROR) and storage-based schemes. Climate change may influence hydropower generation through changed water availability and distribution. If stream flows are reduced, less power will be generated and vice versa. Further, if the flows are concentrated in fewer months, there will be more chances of spill and less hydropower will be generated. If the precipitation in the higher reaches is reduced, less hydropower can be generated in a cascade system of plants. Hydropower stations with storage will be able to accommodate increased seasonality in inflows, but the ROR schemes will be more vulnerable to climate change. Climate change could also induce a timing mismatch between energy generation and demand.

Since the solubility of gases and rate of biological processes change with temperature, water quality is impacted by changing temperature. Altered water temperature in reservoirs and lakes influences the potential for algal blooms, which can further reduce oxygen levels[1]. Changes in water availability may affect concentrations of suspended sediment, nutrients and chemical contaminants in rivers and lakes. Changes in precipitation intensity and frequency will also influence non-point source pollution. Water acquires most of its geo- and biochemical additives during its cycle from clouds to rivers. Changes in the amounts or patterns of precipitation will change the route/residence time of water in the watershed, thereby affecting its quality. In areas with relatively high water tables, or under intensive irrigation, increased evaporation due to higher temperature will raise the concentration of dissolved salts. Further, increased flooding could raise the water tables to the point where agrochemicals/industrial wastes from the soil leach into the groundwater supply. Higher ocean levels will lead to saltwater intrusion in coastal aquifers, threatening the availability of freshwater for the people.

The increase in natural disasters (floods and droughts) will further complicate issues of water availability and quality. Of particular concern are increased risks from flooding. IPCC has projected that flooding and landslides pose the most widespread direct risk to human settlements from climate change. The United Nations Framework Convention on Climate Change (UNFCCC) predicts more severe storms and floods along the world's increasingly crowded coastlines. Beyond the devastation, including loss of life and livelihood, flooding has major impacts on water resources, and hence humans.

The health implications of changes to water supply are far-reaching. Currently, more than 3 million people die each year from avoidable water-related disease. Climate change may worsen the existing ill-effects of water contamination on human health (www.wmo.int), as follows:

- Water-borne diseases: resulting from the contamination of water by human/animal faeces, or by urine infected with pathogenic viruses/bacteria. These are more likely to occur during periods of flood and will intensify with the projected increase in natural disasters.
- Water-washed diseases: resulting from inadequate personal hygiene as a result of scarcity or inaccessibility of water (including many water-borne diseases and typhus).
- Water-based diseases: caused by parasites that use intermediate hosts living in/near water.
- Water-related diseases: borne by insect vectors having habitats in/near water (e.g. malaria).
- Water-dispersed diseases: infections for which the agents proliferate in freshwater and enter the human body through the respiratory tract.

Falling water quantity and quality will require people, particularly women and children, to spend more time to gather water, detracting from employment, education and playing opportunities. A greater proportion of household income may need to be spent on water delivered from private sources, such as tankers, to supplement the municipal supply. Since water is a key input to industrial uses, reduction in availability will reduce industrial production or make them more expensive. For example, recent past has seen instances when thermal power plants had to be shutdown due to non-availability of cooling water. Climate changes will affect all, rich and poor, developed, developing and under-developed countries, but with different force. Further, the affected societies will have different capacities to cope with.

Climate change, however, will not introduce just an additional complexity; many of the assumptions in hydrologic analysis will also require a relook. For example, the design and management of hydro-infrastructure assumes that the underlying climate and hydrologic processes are stationary, even if their statistics is not perfectly known[13]. Hydrologists traditionally assume the hydrologic phenomena such as floods and droughts at a location to be independent and identically distributed. While non-stationarities in the processes due to land-use/land-cover changes have been recognized in the past, impacts of anthropogenic activities on climate and the nature of catchment response is of concern now. It is important for the profession to review and revise the design and operation methods, and account for climate-related risk. Impact of climate change on water-related sectors was aptly summarized by IPCC while stating that 'water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change'.

Overarching actions for India to tackle climate change impacts

Integrated actions to adapt to climate change and mitigate its adverse consequences involving water and related resources are urgently needed in India. These can be practised through six overarching actions as follows.

1. Data observation and information dissemination: A network of hydrometrological stations should be identified where baseline data for climate change studies can be collected. Information and knowledge for local adaptation must be improved, and be freely shared to receive inputs of all stakeholders. A change in mindset is required because many people consider knowledge to be power and suppress information sharing.

2. Integrated water resources management (IWRM): Various water uses for river basins will compete with each other in future. IWRM appears to be the best strategy to overcome the adverse impacts of climate and other changes.

3. Sustainable development: Adaptation in the water sector must be addressed in a broader national development context, recognizing climate change as an added challenge to food and energy production, controlling the hazards, maintaining water quality of natural resources, preventing environmental degradation, and rapid socio-economic development. The National Action Plan on Climate Change of the Government of India (2008) is an example of such broad-based thinking.

4. Water governance: Strengthening institutions for water management is crucial for effective adaptation. Among other things, this requires that the rules and regulations are based on scientific conclusions, are clear, implementation is unbiased, and there is no corruption. Timely completion of various projects should be ensured.

5. Adaptation and mitigation: Adaptation to climate change refers to changes in the ways the society uses natural resources. Mitigation focuses on tackling the causes of climate change. Both have their own role and importance in solving the problem.

6. Financing: Higher and timely financing will be required. The cost of inaction or delays could be quite high. It will help if the private sector can be roped into support some activities.

A discussion on each of these actions follows.

Data observation and information dissemination

Monitoring networks are essential to fully understand the hydrologic processes that govern availability of water, its optimal utilization, to calibrate and validate hydrologic models used for design and management, forecasting, to detect changes, etc. Timely information about the likely future changes in the hydrologic regime and associated sectors enables preparation of effective plans and implementation of the best strategies for development. Since considerable attention has been paid to this topic in the past, a few additional important issues are highlighted here.

To determine the changes in the hydrologic systems which may arise due to climate or land-use/land-cover changes, it is essential to have long-term baseline data from the monitoring networks. Baseline data are of prime importance in any change detection and inter-comparison study. Hydro-climate databases in India suffer from several deficiencies: (i) the network is sparse in many places, particularly in mountains which are our water towers and where the climate has immense variability; (ii) we have fairly long time-series of meteorological data but very few stations have long series of hydrologic data; (iii) time-series data may have long gaps and the quality of the data is uncertain and (iv) it is a tedious and time-consuming process to lay hands on data and in most studies, considerable time is spent on obtaining the requisite data.

Many countries such as USA[14] have identified baseline data networks. It would be important for India also to identify a network of baseline stations (weather stations, stream gauging sites, groundwater monitoring stations and water quality stations) for change detection and other studies. Existing stations with long series of good quality data will be the obvious candidates for the baseline network. In addition, it will be necessary to add new stations keeping in view the water availability and utilization, hydrologic hazards, condition of the environment, etc., so that the hydro-meteorological variabilities over the whole country are properly represented. Observed data should be freely available to the users, so that they are put to optimum use in planning and management.

IWRM

Various water uses for river basins (for example, irrigation, energy generation and environmental flows) will compete or be in conflict with each other in future, thus creating additional management problems. In fact, this conflict can be already noticed in many areas. Severity of the problem increases many folds if water is scarce and/or its quality is deteriorating, as is happening in some basins such as the Ganga, Yamuna, Pennar, etc. Developers of energy or the farm sector desire to use most of the river flows for their needs, whereas proponents of the environment oppose this on the grounds that it is destroying the rivers.

IWRM appears to be the best approach to overcome the adverse impacts of climate change, land-use/land-cover changes and demographic drivers. IPCC[15] states that 'it can be expected that the paradigm of IWRM will be increasingly followed around the world which will move water, as a resource and a habitat, into the centre of policy making. This is likely to decrease the vulnerability of freshwater systems to climate change'. In India, IWRM will have to be strengthened by making and implementing appropriate laws.

Sustainable management of water requires integration, recognizing the interconnections between various sources, and upstream and downstream. Scientific inputs which are essential to water management in the context of river basins currently come principally through hydrologic modelling. However, many issues cannot be understood or defined from one particular perspective alone and limitations arise due to this. Even when the importance of context and multiple perspectives is recognized, policy makers may struggle to develop a more holistic or systemic view of the interdependency between individual actions and catchment[16]. Scientific understanding is essential and forms the foundation, but in IWRM it is one pillar of decision making. Management of water requires more systemic approaches to involve multiple stakeholders in formulating a policy and its implementation. System-oriented models could enhance dialogue and facilitate work across various scales so as to increase focus on the 'whole picture'.

The benefits of an integrated management system for the environment are immense. Dzwairo *et al.*[17] argue that a holistic approach to water management is beneficial for the environment only if it takes cognizance of environmental concerns. Several practical examples from the different parts of the world make a strong case for IWRM to be an effective approach for sustainable management at river-basin level. Van der Zaag[18] also believes that the implementation of IWRM is a 'must', because systematically pursuing IWRM constitutes a path of short-term risk that leads to long-term security. Current and future environmental and developmental needs can be best met by management of water resources in a holistic manner, which is what IWRM is all about. Enormous benefits could be gained from integrating the management of natural and human systems.

Operationalizing and implementing the IWRM approach in practice, however, is a big challenge. Insufficient networking and collaboration between the different government departments and the practices of different water-use sectors is the major reason behind the non-implementation or limited successes of IWRM in India. For instance, rather than estimating total water availability at a place, surface water and groundwater are assessed separately in India. In addition, about a dozen different ministries look after the different aspects of water management, with little cooperation among them.

To make the concept of IWRM implementable, the difficulty in integrating the actions of different sectors (agriculture, energy, environment, etc.) has to be overcome. The IWRM process should be driven by local interests and should address real needs without which it cannot work[17].

The International Water Management Institute (IWMI)[19,20] analysed challenges that are faced by IWRM in developing countries and reported that what usually gets passed-off in the name of IWRM at the operational level, is a rather narrow view of the philosophy. According to IWMI[19], some reasons behind ineffective IWRM in developing countries with particular reference to India are: (i) the uniquely informal nature of developing-country water economies; (ii) transformation of informal water economies with overall economic growth; (iii) institutional environment versus institutional arrangements; (iv) Interventions with poor implementation efficacy; (v) promising but transaction-costly interventions and (vi) vibrant but ignored institutional innovations.

For effective IWRM, it is necessary to overcome the above drawbacks and fragmentation in water management at the central government and state government levels. All decisions related with water, from supply to treatment, should be taken and implemented in a coordinated manner.

Sustainable development

Although many definitions of the term sustainable development (SD) are in use, in simple terms, SD is a pattern of resource use that aims to meet the current human needs, while preserving natural resources and ecosystems on which the current and future generations depend. Freshwater sources are of crucial importance to sustain biodiversity which is increasingly threatened by careless exploitation of natural resources. Pollution of water bodies is becoming widespread. Dams, diversion and overexploitation are affecting the world's freshwater habitats which are among the most productive sources of protein. These impacts are responsible for the progressive degradation of inland freshwater systems.

Enough water of good quality should always be present in the rivers so that aquatic life and biodiversity does not suffer. In many rivers, base flows have dramatically reduced over time due to fall in the groundwater table. Rejuvenation of aquifers is necessary for rejuvenation of rivers. Two aspects of SD are presented here, followed by a discussion on *cumulative impact assessment* (CIA) which can help in comprehensive evaluation of a river basin development plan and suggest pro-active actions that need to be taken to avoid damages.

Environmental flow requirements: Health of a river ecosystem depends on many factors. These are: discharge in the river, physical structure of the channel and riparian zone, quality of water, channel management such as macrophyte cutting and dredging, level of exploitation (e.g. fishing) and the presence of physical barriers to connectivity[21]. Any changes in the flow regime will have some influence on the river. However, most river ecosystems are managed to different degrees to meet the needs of the society. Certain needs, e.g. water supply for municipal uses and irrigation, require removal of water from the river, whereas needs such as bathing in the river do not require removal. As more water is abstracted from a river, economic gains increase, but so does environmental degradation (Figure 1). When abstraction is low, environmental degradation is marginal but gains are high. As the abstraction increases, the incremental gains are lesser but degradation is higher.

In the 1970s, the concept of minimum flow in the rivers came into practice, based on the premise that the health of a river ecosystem deteriorates if the flow falls below a minimum value. Subsequent studies led to the understanding that minimum flow alone is not sufficient and all elements of a flow regime, including high, medium and low flows are important[22]. Increasing freshwater demands for agricultural, domestic and industrial uses has led to the perception of many developers that freshwater flowing to the oceans is a loss. But some flow in the rivers is necessary to maintain its health and biodiversity.

Adverse impacts from storage and diversion can be minimized by releasing water to meet the environmental flow requirement (EFR). EFRs are those flows that are needed to maintain aquatic ecosystems, renewable natural resources production systems and associated livelihoods. As such, EFR is a compromise between water resources development and maintenance of a river in ecologically acceptable or agreed conditions (Figure 1). EFR depends on the size of the rivers, natural state, desired state, sensitivity of river ecosystem, preference of the society and uses of river water. Water Framework Directive (WFD) of the European Union requires Members States to achieve 'good status' (GS) in all surfaces and groundwaters (http://ec.europa.eu/environment/water/water-framework/index_en.html). Good status of a river is a combination of good chemical status and good ecological status (ES), and these are defined by WFD. No such benchmarks exist for India.

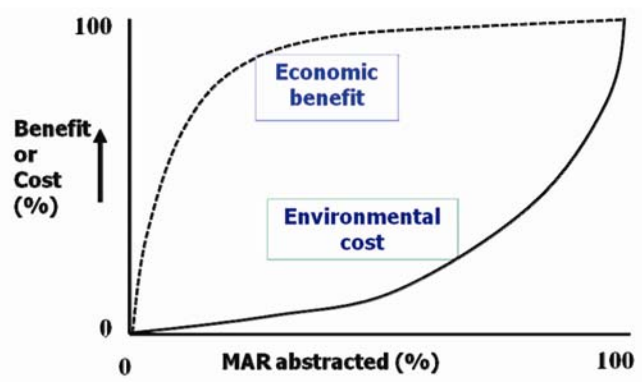

Figure 1. Graph showing typical pattern of environmental cost and economic benefit as functions of flow abstracted from a river. MAR, Mean annual run-off.

Since the mid-1970s, there has been a proliferation of methods to estimate environmental flow for a river, ranging from relatively simple, low-confidence desktop approaches to resource-intensive, high-confidence approaches[23]. The comprehensive methods are based on detailed multidisciplinary studies that often involve expert discussions and collection of large amounts of geomorphological and ecological data. The various approaches developed to estimate environmental flow requirements can be divided into four broad categories: hydrological index method, hydraulic rating methods, habitat simulation methodologies and holistic methodologies.

A study on EFRs of Indian river basins was carried out by Smakhtin and Anputhas[24]. They estimated EFR for 13 major river basins of India. Many more studies on this topic have been completed recently. Quantum of flow recommended as EFR for a river may vary from about 5% of mean annual flow to as high as 70% (ref. 25). EFR can be interpreted to be a balance between development and conservation, and for a given river basin all the stakeholders, including the government, private developers, political leaders, NGOs, etc. should jointly decide how much water needs to be allocated for EFR. Realizing the importance of EFR, many countries have formulated policies to ensure priority allocation of water to river ecosystems after the basic human needs are satisfied.

Fragmentation of rivers and loss of biodiversity: River fragmentation refers to the degree to which the river system is spatially broken. This is classified according to the longest segment of the main river channel without dams and whether dams exist in the major tributary, minor tributaries or both. Flow regulation is the degree to which the virgin mean annual discharge (VMAD) is regulated by dams or other diversions. It is computed as the sum of reservoir capacity within a river system, expressed as the percentage of VMAD which can be contained by the reservoirs. VMAD of a river system is the discharge (in m^3/s) for the most water-rich river segment, before any significant direct human manipulation.

Nilsson *et al.*[26] studied fragmentation and flow regulation in the large river systems (LRSs) of the world. The Indian rivers that are reported to be strongly fragmented included Mahanadi, Brahmani, Krishna, Godavari, Cauvery, Periyar, Tapi, Narmada, Mahi and Indus. The rivers were classified in three groups based on exploitation of water and a combination of fragmentation and flow regulation assessments: not affected, moderately affected and strongly affected.

Vorosmarty *et al.*[27] presented the results of a global-scale analysis of threats to freshwater, which simultaneously considered human water security and biodiversity perspectives. They found that nearly 80% (4.8 billion) of the world's population (for year 2000) lives in areas where either incident human water security or biodiversity threat exceeds the 75th percentile. According to the authors, most of Africa, large areas in central Asia and countries, including India are regions of greatest adjusted human water security threat. Problems due to river fragmentations are likely to further increase due to higher withdrawals and diversion from Indian rivers.

The main challenge for the developing countries, including India is to establish human water security while preserving biodiversity, and this can be best met through IWRM and balancing the needs of humans and nature. Although there have been set-backs in the past, it is possible to preserve and rehabilitate ecosystems. For instance, the reservoir operating rules can be modified and a balance can be found that maintains economic benefits while simultaneously allowing environmental flows.

CIA: Many countries have made environment impact assessment (EIA) an integral part of any infrastructure development project for the sake of sustainable development. Projects that are likely to cause significant adverse impact to the environment are not approved. However, it is now realized that while the impacts due to individual projects may not be large, cumulative impacts of a group of projects may be significant. Therefore, many countries and donor organizations insist upon CIA for river basin development plans. Cumulative impacts on the environment result from the incremental impacts of the actions (past, present and foreseeable future) regardless of who undertakes the actions. These relate to the integrated impacts over time on each relevant environmental resource, ultimately affecting human beings living in the basin and the areas influenced by the project. Note that the impacts may be additive, subtractive or neutralizing.

According to Canter[28], an important aspect of CIA is to identify the valued ecosystem components (VECs), which are the elements of the environment (natural or social) that are valued by the public and/or specialists in the area. Examples include variability of flows, soil erosion, groundwater and spring flows. Before taking up any CIA study, it is important to define spatial and temporal boundaries of the study area, describe past baseline conditions for each project and properly consider the existence of legal constraints. VECs are best chosen by consultation.

Among the other benefits, CIA helps in establishing monitoring programmes for the projects. Such studies have led to the adoption of a regional and historic perspective that is usually missing in EIAs. Going one step further, it appears that CIA also may not fully reflect the impacts of the projects in the event of climate and land-use/land-cover changes. Hence impact assessment studies should also consider the additional impacts that are likely to arise in the event of changes in climate and land use/land cover. Such assessments can be termed as CIA with climate change or (CIA+). Developmental activities that are taken up after assimilating the findings of CIA+ are likely to be truly sustainable.

Water governance

Due to reasons such as growing population, industrializations, etc. per capita water availability is dwindling in most developing countries. At the same time, quality of water is also deteriorating. Hence we frequently hear that the world is in the grip of a 'water crisis'. But a closer look at the situation shows that it is more a water governance crisis which has arisen due to mismanagement of water and unscientific policies. Now, we have additional problems due to climate change. In a way, the water governance crisis and climate change crisis have many similarities: (i) both of these have been created largely by human actions; (ii) adverse impacts of both are mostly additive in nature and (iii) both affect all the living beings, i.e. humans, terrestrial and aquatic life, and plant life.

The United Nations Development Programme (UNDP)[29] has clearly conveyed the message of water governance crisis through the cover design of the Human Development Report for 2006 (Figure 2), which captures the idea that millions of the world's people lack access to safe water not because of scarcity, but because they are locked out by poverty, inequality and government failures. Tackling these problems holds the key to resolving the global water crisis and adverse impacts of climate change.

Climate change will impact water availability at a place or region for various uses such as environmental needs, municipal and industrial, irrigation and hydropower. Since the variability of the precipitation and thereby that of the discharge is likely to increase, it will be necessary to be able to regulate the river flows to a larger extent. This can be best achieved by creating more water-storage capacity in the country and optimally use the storage space. The existing water infrastructure is inadequate to accommodate the magnitude and temporal patterns of stream flows. Besides changing the pattern of water availability at a place in accordance with the demands, storage schemes can also generate hydroelectric power and help in controlling floods. In addition, conjunctive use of surface and groundwater will be immensely useful to improve agriculture productivity. In areas that experience a decrease in water availability, competition for water among users will increase. Decreased water

Figure 2. Water governance crisis, as depicted by UNDP[29].

supplies could adversely affect economic development, recreational opportunities or habitat. Carefully prepared inter-basin water transfer schemes can help in the alleviation of the problem.

Flood-control structures, water-system operational strategies and resource management decisions may face more intense rainstorms, more events of rain on snow, and greater portions of watersheds participating in winter rainfall-run-off generation[1,2]. These changes may create more frequent and more severe flooding of some rivers. However, because of uncertainties in climate models and flood-record analyses, the nature of changes in specific locations remains uncertain and will require detailed study. The design and evaluation of flood risk-reduction infrastructure should use the most recent available data and consider possible future climate conditions, including shifts in the seasonal timing of high flows. Stormwater infrastructure may need to factor in climate change effects (including rainfall intensities) in design and operation. For example, the stormwater infrastructure in Mumbai city has proven to be inadequate to safely drain out the waters during high-intensity events.

Generation of hydropower and demand of electricity are especially sensitive to climate change[1]. These effects are magnified in regions where both heating and cooling are required. Ice-storm frequency or intensity, as well as permafrost extent affect the energy infrastructure and consumption. Hydropower generation will be affected by changes in water availability, particularly in snowmelt-dominated basins, such as Sutlej and Ganga. Hydropower production in projects that are operated to meet multiple objectives (for example, flood-control, irrigation, municipal and industrial water supply) will be affected depending upon the system configuration and operation procedures.

Like any other infrastructure, maintenance of hydro-projects (embankments, dams, barrages, etc.) is essential if it is to continue to provide the planned and desired level of services. Neglect of maintenance accelerates the degradation and deterioration of any infrastructure. Increased incidences of extreme events due to climate change will put the infrastructure under additional stress. In India, many dams and canals are more than 50 years old. Hence careful attention is required to rehabilitate the old infrastructure and enhance its capabilities, wherever feasible and necessary.

Adaptation and mitigation

Adaptation to climate change is basically concerned with the way the natural resources are used by the society and mitigation is concerned with dealing with the causes of climate change. According to Clausen and Bjerg[10], 'if mitigation is about energy, adaptation is about water'. International negotiations have chiefly focused on mitigation and the reason behind it is that unless there are binding global agreements and treaties, it will not be possible to control the climate in any worthwhile manner.

Adaptation to climate change is concerned with how to deal with the impacts of climate change: those already observed and those that are likely to happen. Structural measures or hardware-based adaptation solutions require considerable financial investments. For instance, countries in North America have build dams to secure food and energy production, protection against floods and storage of water to increase dry-season water security and reduce the impacts of drought. In Africa and parts of Asia, with monsoon climates and a much higher hydrologic variability, storage capacity is much smaller. For example, per capita storage capacity in India is 262 m^3; it is 6150 m^3 in North America, 6013 in Russia, 4729 in Australia, 2486 in China and 40 m^3 in Ethiopia. Hence to build robustness to climate variability (existing and future) and to overcome water scarcity in India, large investments are required in water infrastructure, e.g. dams, canals and dikes. It will be necessary that all aspects of water resources management, including infrastructure development and non-structural instruments, water saving and new water sources development are strengthened to solve the current water problems and prepare to adapt to future changes.

Detailed atmospheric modelling shows that in West Africa in the near future, the onset of rainy season will shift to later periods in a year[30]. This implies that adaptation strategies should be twofold. The first part of a comprehensive adaptation strategy would be a continuation of the efforts to produce faster growing rainfed crop cultivars, mainly corn and sorghum. The second part would consist of increased water storage during the wet season for use during the dry season.

Adaptive policies were tested by Ghosh *et al.*[31] for the Hirakud reservoir for two extreme scenarios showing largest reductions in hydropower generation for the period 2045–2065, viz. MIROC B1 scenario and CGCM2 A1B scenario. The first policy aims to restore performance with respect to power generation by decreasing other demands – in this study, irrigation demands. The second policy explores how changes in flood control rules could be used to restore performance. Feedback from this type of analysis can be gainfully used in updating the operation policies of existing projects.

Many measures address the existing problems and at the same time build resilience for the future. Flood and drought management is one pertinent example; others include less water intensive agricultural practices to conserve water; reduce domestic and industrial water demand through pricing and water conservation and measures to reduce the 'water footprints' of energy production. CGIAR estimates that 75% of the additional food needed over the next decades could be grown by bringing the production levels of the world's low-yield farmers up to 80% of what high-yield farmers get from comparable land[19].

In the coastal zone, three options to overcome water-related problems are often mentioned: protect, adapt or relocate. We can build new projects and 'climate proof' the existing infrastructure; we can try to change our lifestyle to better live with changes; or people can be moved to other safer places. Such actions which should have been taken in any case are commonly termed as 'no regret' solutions. All adaptation challenges, however, are not 'no regret' and one cannot always avoid hard decisions. Notwithstanding the uncertainty involved, design measures specifically to address expected future climate impacts need to be undertaken. Sea-level rise on the Dutch coast, for example, can be addressed only by building more infrastructure for which finances and other resources are available. But for Bangladesh, the problem has a different dimension due to socio-economic conditions.

Adaptation measures can be divided in several groups, 'hard' and 'soft'. A combination of measures will often be required. One such option, for example, is the 3R measure: recharging the groundwater; increase retention by watershed management, and reuse and recycle of water. Kolokytha[32] has described a number of mechanisms that can facilitate adaptation efforts and optimum use of water in Europe. These include the European Union Water Framework Directive (EUWFD), the Flood Directive, the Marine Strategy Directive and the new Common Agricultural Policy (CAP). According to a recent directive, all EU Member States are required to focus on the assessment and management of floods. Performance of preliminary flood risk assessment, evaluating the extent of possible extreme events in the future which includes climate change impacts, development of flood maps and provision of Flood Risk Management Plans by 2015 are the main components of the directive.

Action on adaptation is needed at all levels of administration – local, regional, national and international – and requires the involvement of public and private sector as well as individuals. Vulnerability to climate change and the severity of its impacts will be unevenly distributed. Effective adaptive measures include[32]:

- water pricing across all sectors for sustainable water use;
- demand management measures which will improve water efficiency and promote water conservation;
- design and application of drought management plans at river-basin scale;
- raising public awareness and information;
- if demand management approach is not adequate, alternative methods such as reuse of water, desalination or treated wastewater are possible solutions, and
- reduction of illegal water use.

Mitigation of climate change aims to find and implement ways to reduce the anthropogenic factors that are responsible for causing changes to the climate by control of emissions of GHGs and land use/land cover primarily by reducing energy consumption or changing the energy mix.

Synergy between adaptation and mitigation: Frequently mitigation and adaptation are seen as separate approaches and addressed by different organizations. However, there is considerable synergy between the two. The benefits in adaptation will increase many folds if synergies between the two are exploited in formulating and preparing plans. Figure 3 illustrates the inter-relationships between adaptation, mitigation and impacts. As more attention is paid to adaptation, cost of mitigation and impacts will reduce and so on.

One well-known interconnection is the water-energy-climate nexus. Electricity demands are increasing fast (at about 8–9% per year in India) and production of all forms of energy requires water. Regarding biofuels, production of 1 litre of bio-ethanol consumes about 3000 litres of water. Hence, the 'water footprints of energy generation' can be significant and have consequences for water management. Conversely, providing water may require energy, resulting in 'energy footprints for water'. Water and energy nexus also demonstrates the inter-connectivity between the two, and it can motivate 'energy smart' water investments and 'water smart' energy investments[10]. This type of approach would contribute to both mitigation and adaptation.

Another example of the potential synergy between mitigation and adaptation is the potential of improved agricultural and land management, and reforestation. It is estimated that 18% of all GHG emissions come from agriculture (Table 1). Deforestation results in reduced

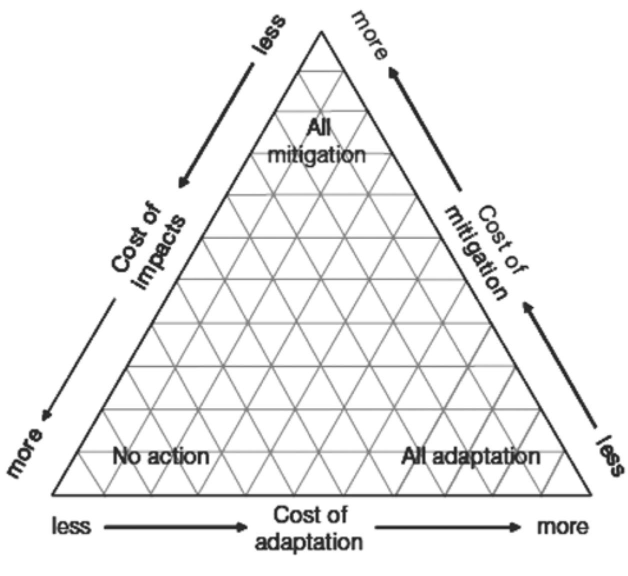

Figure 3. A schematic overview of inter-relationships between adaptation, mitigation and impacts (source: Klein *et al.*[35]).

carbon sequestration (carbon absorbed by the plants). When forests are cleared and the land is exposed to rain and wind, soil erosion increases. Soil conservation, reforestation and improved agriculture practices contribute to carbon sequestration. Through improved agricultural and land management, improved agricultural water management, selection of drought-resistant crops, afforestation, etc., the rural population may adapt to climate change.

Other synergistic options are change in lifestyle and the way we live, for example, avoiding the use of cars and switching to public transport, use of locally produced materials/food. Since production of meat requires much more water than foodgrains, people can contribute to both mitigation and adaptation by adopting vegetarian diets.

Financing

Although there is great uncertainty about future climate change and not enough information is available to plan future actions, suitable actions have to start before it is too late. Lack of information is no excuse for delayed actions and a wide range of 'no regret' actions can be initiated immediately.

Stern review[33] has estimated that the annual global investments needed to avoid the worst impacts of climate change could be limited to 1% of global gross production each year, if action starts now. The cost of inaction would be equivalent to losing at least 5% of global GDP each year. The political will to act and allocate priorities and resources towards this endeavour depends on awareness and understanding of the adaptation issue.

State action plans: The impacts of climate change and the adaptation measures required span a wide range, from the panchayat level where people can themselves decide how to adapt to changing circumstances, through actions at the national level, to international cooperation between countries sharing the same river basin. Again, the success of the National Action Plan of India requires collaboration between various ministries as well as involvement of people through public–private partnership. Of course, a potential weakness of this programme is that it is a top-down effort and a similar bottom-up process is needed. State-level action plans are being developed in many states and this is an opportunity to involve a wider cross-section of the society in the whole effort.

We may also be cautious about corruption. According to the report in Outlook India (http://www.outlookindia.com/, 21 March 2011), inspections by CAG teams have revealed that many of the completed projects under the Accelerated Irrigation Benefit Programme (AIBP) exist only on paper. In many cases, there is no way the water from the source can reach the farmers due to varied problems, ranging from missing links to improper planning and construction to the water passage being clogged by vegetation and/or silt. A general perception is that corruption is one of the reasons behind time and cost overruns of the projects in the water sector, apart from the shoddy quality of construction and maintenance.

Final remarks

Even without climate change, many regions of the world are already water stressed and face challenges to ensure food production and other water-related services for a fast-growing world population. Climate change is an added driver, acting on population increase, economic growth and urbanization. Put together, all of these stress water resources even more. Mitigating the causes of global warming by limiting emissions of GHGs has been the main focus and obstacle, but during international negotiations the need to also address the impacts of climate change through adaptation has increasingly been acknowledged. As pointed out by Kojiri[34], water-related issues such as system dynamics, downscaling, river-basin simulation and economic damage must be discussed to understand the impact, linking it with human actions, and the need for interdisciplinary collaborations.

The main impacts of climate change will 'hit us through water' through changes in the magnitude of water balance components, increased incidences of floods and droughts, and sea-level rise. Addressing these impacts is a matter of urgency for a vulnerable country like India. One can also take a positive view of climate change: it has acted as a wake-up call for the decision makers to address existing challenges which will become more intense with global warming. The poor people are already suffering since they have limited ability to cope with the existing climate variability. Addressing the immediate problems will definitely help our weaker section and we to also build resilience for an uncertain future. Such actions are termed 'no regret' initiatives. Unfortunately, not enough no-regret actions are being taken. Infrastructure such as dams, dikes, etc. needs to be constructed and complemented with 'soft' actions to reduce the pressure on natural resources and conserve them. All this is to be done with adequate knowledge and by employing adaptive management.

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