HUMAN DISRUPTION

SCENARIO

Climate Change and Water Resources

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Flood and drought management schemes have to be planned keeping in view the increase in severity of floods and droughts. It would be prudent to incorporate possible effects of climate changes in the design and management of water resources systems. The high magnitude floods are also likely to bring more sediment which may fill reservoir space. The design and management of both structural and non-structural water-resource systems should allow for the possible effects of climate change

Climate of a region represents the long-term (more than thirty years) average of weather. It is a resultant of an extremely complex system consisting of different meteorological variables which vary with time. Climate may be defined as "average weather" or more as the statistical description in terms of mean and variability of relevant weather variables over a period of time.

Climate change (CC) refers to a statistically significant change in either the mean state of the climate or its statistical properties (such as standard deviations, the occurrence of extremes, etc.), persisting for an extended period particularly decades or longer. Climate change is not only a major global environmental problem, but also an issue of great worry to a country like India.

Causes of Climate Change

CC can take place due to forcings that may be external to Earth or internal. Two external forcings are important. Earth's orbit and tilt of its rotational axis are changing slowly, caused by gravitational forces of other planets and orbit of solar system about the centre of Galaxy. 'Milankovitch Cycles' is the collective name for cycles in Earth's movement. Changes in these cycles cause very slow and long-term climate change. Three types of orbital variations are identified. Tilt of Earth's axis with respect to plane of orbit varies between 22.1° to 24.5° in about 41,000 years. The tilt does not impact total solar radiation received, but the space and time distribution changes. Next, axial precession is the gradual shift in orientation of Earth's axis of rotation relative to fixed stars, in a cycle of $\approx$26,000 years. When this axis is aligned to point towards Sun during perihelion, one polar hemisphere will have a greater difference between seasons while the other will have milder seasons. Finally, eccentricity of Earth's orbit around the Sun controls shape of Earth's orbit around Sun and the radiation received.

Internal forcing mechanisms of CC operate within the climate system. Great volcanic eruptions release huge amounts of gases, ash and aerosols and impact climate by reducing solar radiation reaching Earth. GHG emissions due to combustion of fossil fuels to generate electricity, heating, and transport account for $\approx$ 70 per cent of total emissions and are the main cause of global warming. Movement of tectonic plates has a direct connection between uplift, atmospheric circulation, and hydrologic cycle.

Greenhouse Effect: Short-wave radiation from the Sun passes through the Earth's atmosphere which contains different gases. A part of this radiation

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is reflected back into space, a part is absorbed by the atmosphere and the remainder reaches the earth's surface where it is either reflected or absorbed. In particular, the earth's surface emits long-wave radiation towards space. Some of the gases in the atmosphere absorb a part of the long-wave radiation emitted by the Earth's surface and re-radiate it back to the Earth, forcing it to warm. These gases help modify the heat balance of the Earth by retaining long-wave radiation that would otherwise be dispersed through the Earth's atmosphere to space (Fig.1). This effect is known as the greenhouse effect and the gases causing this are called greenhouse gases (GHGs). The principle greenhouse gases present in the atmosphere include carbon dioxide (CO_2), nitrous oxide (NO_2), methane (CH_4), water vapour, chlorofluorocarbons (CFCs) and ozone (O_3).

Obviously, GHGs have an important role in controlling the temperature of the Earth and keeping it sufficiently warm for life to survive but excess of these gases is having harmful consequences. An increase in the levels of GHGs would lead to greater warming which could have major impact on the world's climate, leading to CC. Fig. 2 shows the gradual rise in concentration of CO_2 in the atmosphere in recent times. Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased from 280 parts per million to 399 ppm, 722 (part per billion) to 1834 ppb and 270 ppb to 328 ppb respectively, between pre-industrial period (1750) and 2015. In addition, presence of excess quantities of CFCs adversely affects the protective ozone layer which deflects the harmful short-wave rays.

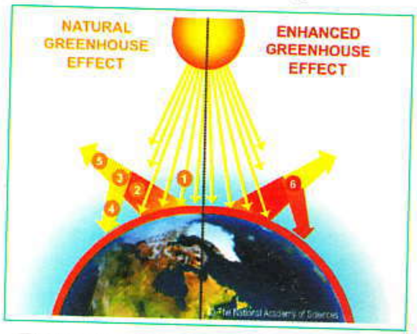

Figure 1: Illustration of the greenhouse effect (Source: National Academy of Sciences). Visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight hitting the earth is (1) absorbed and converted to infrared radiation (heat). The surface (2) emits infrared radiation to the atmosphere, where some of it (3) is absorbed by GHGs and (4) re-emitted toward the surface; some of the infrared radiation is not trapped by GHGs and (5) escapes into space. Human activities that emit additional GHGs to the atmosphere (6) increase the amount of infrared radiation that gets absorbed before escaping to space, thus enhancing the greenhouse effect and amplifying the warming of the earth.

Evidence of Climate Change

The Fifth Assessment Report of IPCC (2015) has produced many evidences which clearly show that global warming is indeed happening. Observed thermometer data at many places on Earth are available back to 1850. Record-high average global surface temperatures have been observed in recent decades. Earth's surface in each of the last three decades has been successively warmer compared to any preceding decade since 1850. IPCC (2014) notes that the period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere. The globally averaged combined land and ocean surface temperature data as calculated by a linear trend shows a warming of 0.85 [0.65 to 1.06] °c over the period 1880 to 2012, when multiple independently produced datasets were used (Fig. 3).

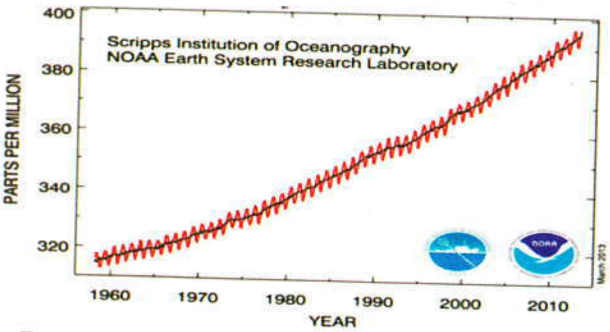

Fig. 2: Changes in concentration of CO_2 in the atmosphere in recent times (Source: NOAA).

Climate Change Impacts On Water Resources

To identify the initiatives that the professionals and decision makers need to take to overcome the adverse impacts of climate change on water resources, first, it is necessary to determine the likely impacts.

General circulation models or global climate models (GCMs) that represent physical and chemical processes in the atmosphere, Cryosphere, land surface, and ocean are the most advanced tools to simulate the response of the global climate system to rising concentrations of GHGs. Although, GCMs are very complex, only these models can provide physically consistent estimates of regional climate change that are required in impact analysis (http://www.ipcc-data.org/guidelines/pages/gcm_guide.html).

GCMs represent the climate using a 3-dimensional grid over the Earth, which typically has horizontal resolution between 250 and 600 km, 10 to 20 vertical layers in the atmosphere and about 30 layers in the oceans. Their resolution is thus, quite coarse relative to the scale at which data are required in most impact assessments. Moreover, many physical processes, such as thunderstorms, occur at smaller scales and cannot be properly modelled by many GCMs. Instead, their properties are averaged over the larger scale by way of parameterization. Different GCMs may simulate quite different responses to the same input forcing depending on the way certain processes and feedbacks are modelled. For example, some models are able to closely simulate the Indian summer monsoon rainfall but many models cannot. Results of GCM simulations are available as time series of climatic variables. For example, hydrologists may be interested in the time series of

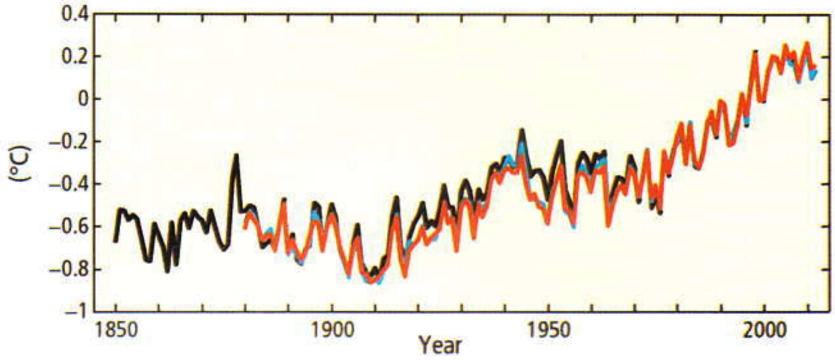

Fig. 3: Globally averaged combined land and ocean surface temperature anomaly (Source: IPCC).

temperature at a location for the period 2025-2075.

To identify the likely impacts of Climate Change on water resources, the following methodology can be followed:

- Select the GCM that closely simulates the climatic variables for the region of interest.
- Downscale (see below) the relevant GCM variables as per the requirement of the chosen hydrologic model.
- Use the hydrologic model to simulate the response of the catchment under future climatic conditions.
- Outputs from the hydrological models serve as inputs to water management models that can be employed for river planning, updating reservoir operation policy, etc.

Downscaling

In climate change studies, the time scales could vary from a short time interval of 5 minutes (for urban water cycle) to a year. Likewise, the spatial resolutions could vary from a few square kilometers (for urban watersheds) to several thousand square kilometers (for large river basins). Global Climate Models (GCMs) which simulate the global climate are among the best available tools to compute the global climatic variables. But these models, so far, are unable to reproduce well the details of regional climate conditions at temporal and spatial scales of relevance to hydrological studies. As noted earlier, outputs from GCMs are usually at a resolution that is too coarse for many climate change impact studies.

Many impact models require information at scales of 10 km or less. So an appropriate method is needed to estimate the smaller-scale information by using the large scale data. Downscaling tries to obtain small-scale (often station level) variables by using larger (GCM) scale variables. In other words, downscaling techniques are commonly used to address the scale mismatch between coarse resolution GCM output and the regional or local catchment scales required for climate change impact assessment and hydrological modeling.

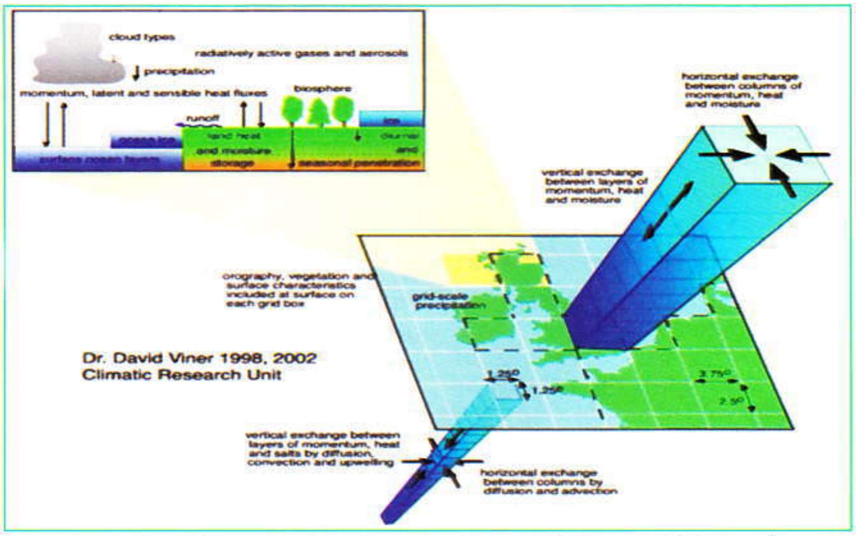

Fig. 4: Discretization scheme used in a GCM (Source: IPCC).

Currently, two broad categories of downscaling procedures are used: a) dynamical downscaling (DD) techniques, involving the extraction of regional scale information from large-scale GCM data based on the modeling of regional climate processes, and b) statistical (or empirical) downscaling (SD) procedures that make use of the empirical relationships between observed (or analyzed) large-scale atmospheric variables and observed (or analyzed) small scale (or stations) data. Fig. 5 depicts the general approach and need for downscaling.

Climate Change: Adaptation and Mitigation

According to IPCC, adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Adaptation can be of different types. Anticipatory or proactive adaptation takes place before impacts of climate change are observed. Adaptation that is not in response to climatic inputs but is triggered by changes in natural systems and by market or welfare changes in human systems is called as autonomous or spontaneous adaptation.

IPCC defines mitigation as: "An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (GHG)." Related to CC, mitigation is any action taken to permanently eliminate or reduce the long-term risk and hazards of climate change to human life and property. Mitigation of climate change is a global responsibility. Agriculture and forestry have significant potential for GHG mitigation. While mitigation

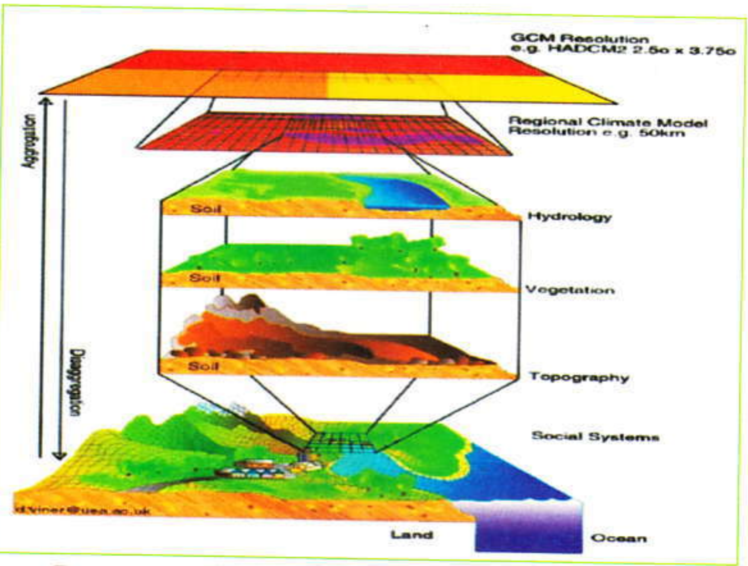

Fig. 5: A schematic illustrating the general approach and need for downscaling (Wilby & Dawson 2007).

tackles the causes of climate change, adaptation tackles its effects. The potential to adjust to minimize negative impact and maximize any benefits from changes in climate is known as adaptive capacity.

In general, the more the mitigation, the less will be the impacts to which the society will have to adjust, and the less the risks for which people will have to be prepared. Conversely, the greater the adaptation, lesser will be the impacts associated with any given level of CC. Adaptation should be viewed as an active adjustment in response to expected changes. Less mitigation means greater climatic change, requiring more adaptation. This is the basis for the urgency surrounding reductions in emission of GHGs. Climate mitigation and adaptation should not be seen as a combined set of actions in an overall strategy to reduce GHG emissions.

Economic diversification within sectors to reduce dependence on climate-sensitive resources, particularly for countries that depend on limited and climate-sensitive economic activities, such as the export of climate-sensitive crops, is an important adaptation strategy. Farmers in India may diversify to tasks related to agriculture, such as dairy business, fish cultivation, fruit preservation, animal husbandry, etc.

Renewable energy systems such as hydro-electricity can help attaining energy security and protect environment. One means of reducing carbon emissions is by larger use of new technologies such as renewable energy (say wind power). Most forms of renewable energy generate no appreciable amounts of GHGs.

Land-use Change and Management

Land management practices implemented for climate change mitigation may also have different impacts on water resources. Many of the practices advocated to conserve soil carbon– reduced tillage, more vegetative cover, greater use of perennial crops – also control erosion and help improve water quality. These practices may also have other potential adverse effects, e.g., enhanced contamination of groundwater with nutrients or pesticides via leaching under reduced tillage. These possible negative effects, however, have not been widely confirmed or quantified, and the extent to which they may offset the environmental benefits of carbon sequestration is uncertain.

Afforestation or Reforestation

Plants are known to take up carbon dioxide in the process of photosynthesis and are sinks of carbon. Therefore, if forests are developed in a region, they will help mitigate climate change. Besides, forests have numerous other benefits including improved environment. It may also be added that the role of forests in the hydrologic cycle is highly context dependent and there are several myths surrounding forests.

In general, forests use more water (transpiration plus evaporation of water intercepted by canopies) than crops, grass, or natural short vegetation. This effect, in lands that are subjected to afforestation or reforestation, may be related to increased interception loss, especially where the canopy is wet for a large proportion of the year or, in drier regions, to the development of more massive root systems, which allow water extraction and use during prolonged dry seasons (IPCC Technical papers).

Newly planted forests can use more water (by transpiration and interception) than the annual rainfall, by mining stored water. Extensive afforestation or reforestation in the dry tropics can therefore, have a serious impact on supplies of groundwater and river flows.

Afforestation and reforestation have many good hydrological effects. After afforestation in wet areas, the amount of direct runoff initially decreases rapidly, then gradually becomes constant, and baseflow increases slowly as age of trees increases (Calder 1990). This suggests that reforestation and afforestation help to reduce small floods and enhance water conservation. In water-limited areas, afforestation involving species with high water demand can significantly reduce streamflow. This may reduce water to other ecosystems elements and affect recharge. In addition, some possible changes in soil properties are largely driven by changes in hydrology. The hydrological benefits of afforestation are highly context dependent. Afforestation of previously eroded or otherwise degraded land may have a net positive environmental impact.

Impact of Climate Change on Indian Water Resources

Availability of numerous water bodies and perennial river systems makes the Indian sub-continent one of the wettest places in the world. Large Himalayan Rivers including Indus, Ganga and Brahmaputra are perennial sources of freshwater though the flow is reduced during non-monsoon periods. Flow in the peninsular rivers mainly depends on the monsoon rainfall and ground water recharge. Changes in temperature, precipitation and other climatic variables are likely to influence the amount and distribution of runoff in Indian rivers. The impact of future climatic change is expected to be more severe in developing countries such as India, whose economy is largely dependent on agriculture and is under stress due to population increase and associated demands for energy, fresh water and food.

The importance of Himalayan river systems can be gauged from the fact that these three river systems contribute more than 60 per cent to the total annual runoff from all the rivers of India. These rivers carry substantial contribution from the melting of snow and glaciers. The runoff of the Himalayan rivers is expected to be highly vulnerable to climate change because warmer climate will increase the melting of snow and ice. Melting of glaciers, and reduction in solid precipitation in mountain regions would have a direct impact on water resources affecting the drinking water, irrigation, hydropower generation and other uses of water. Glacial melt is expected to increase under changed climate conditions, which would lead to increased summer flows in some river systems for a few decades, followed by a reduction in flow in case glaciers retreat continuously.

With an economy closely linked to its natural resource base and climatically sensitive sectors such as agriculture, water and forestry, India may face a major threat because of the projected change in climate. It is likely that the frequency of floods and droughts will increase during the 21st century. Changes in the amount, patterns and intensity of rainfall would affect stream flow and the demand for water. High flood levels can cause substantial damage to key economic sectors: agriculture, infrastructure and housing. Although, floods affect people of all socio-economic status, the rural and urban poor are the hardest hit. Flood and drought management schemes have to be planned keeping in view the increase in severity of floods and droughts. It would be prudent to incorporate possible effects of climate changes in the design and management of water resources systems. The high magnitude floods are also likely to bring more sediment which may fill reservoir space. The design and management of both structural and non-structural water-resource systems should allow for the possible effects of climate change. Despite uncertainties, possibility of changes in such extreme events is quite alarming.

Actions Needed:

1. Improve hydro-meteorological network for better monitoring.
2. Update basin wise water availability in the current situation.
3. Determining extent of current climatic/hydro-meteorological variability and future projections in variability due to climate change including the impact on rainfall frequency and intensity.
4. Generate reliable downscaling of GCM projections to regional and basin level.
5. Assess impact of CC on surface and ground water availability and their interaction (with specific emphasis on coastal areas).
6. Assess impact of CC on Land-Use/ Land-Cover and their coupled impact on water resources.
7. Assess impact of CC on rainfall Intensity-Duration-Frequency relationships in urban areas.
8. Assess impact on magnitude-duration-frequency of drought (agricultural, meteorological and hydrological).
9. Assess impact on sediment loads and management implications.
10. Review hydrological planning design, and operating standards in view of changed scenario.
11. To cope up with enhanced scarcity and variability in the water sector, develop adequate infrastructure.
12. Develop databases and tool-boxes and practice Integrated Water Resources Management (IWRM).

Conclusion

Scientific understanding of the causes of climate change has progressed dramatically in the past few years. Natural internal variability is an inherent feature of the climate system, but it cannot account for the net gain of energy that has been detected within the climate system as a whole. Based on physical principles, the modern increase in the heat content of the global ocean demonstrates that positive external forcing of the climate is underway. Changes in natural external forcings cannot explain the observed global warming of recent decades. Records of observed climate change at the Earth's surface, in the global ocean, and in the atmosphere, bear the fingerprint of the enhanced greenhouse effect, which is caused by human activities associated with fossil fuel burning and land use.

Readings

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