Impact of Climate Change on Hydrology and Water Resources in India

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Abstract On a regional scale, some of the most profound impacts of climate change due to increases in greenhouse gases would probably be major changes in the hydrological cycle, in water availability, in agricultural production and in the use of energy. This paper gives a brief overview of studies carried out on climate change and possible impacts on hydrology and water resources in India, covering also the agricultural aspect. The need is emphasized for carrying out further studies in this important subject area at the national level, keeping in view the data and computing facilities available.

Introduction

Possible future climate change due to increases in greenhouse gases has attracted the attention of scientific workers and policy makers in recent years. Research activities in this area have been carried out by various groups, notably in the United States, Canada, Germany, the United Kingdom and Australia, and have been coordinated by the World Meteorological Organization (WMO), the United Nations Environmental Programme (UNEP) and the International Council of Scientific Unions (ICSU) (WMO, 1986; IPCC, 1990), Conferences were held in Villach (1985), Toronto (1988), New Delhi (1989), Hamburg (1989) and Helsinki (1989), with the aim of bringing together experts involved in projects concerned with climate variability and change, their impact on hydrology and water resources, and to identify the problems in this area.

Indian climate

The major impacts of climate change in India would be on the hydrology, water resources and agriculture of the country. A rise in sea level due to thermal expansion of sea water and melting of ice form high altitudes and latitudes is also expected. Climate variability and climate changes assume great importance for the Indian sub-continent because its economic performance and social progress are dependent on rainfall and climate change is likely to affect rainfall. India possesses a great variety and diversity of climate, varying form extremely hot to extremely clod, from extremely arid regions to extremely humid regions, from drought-prone areas to flood-prone areas. Climatic conditions govern to a great extent the operation of water resources in the country. The Himalayan rivers of India are ice-fed rivers and thus are very vulnerable to climate change. Rainfall is governed by the southwest and northeast monsoons. The distribution of Indian rainfall shows great temporal and spatial variations. About 80% of the total rainfall occurs during four monsoon months (June to September) and is not spread uniformly over the country, creating pockets of scarcity in some regions. Thus, large storages of water are required to meet the demand during the lean periods.

Agriculture is the dominant sector in the economics of a developing country like India and is the major source of employment, income and sustenance for the majority of the population of the of the country. Out of the 342 X 10^6 ha of land area in India, 142 X 10^6 ha are cultivated, out of which 31.4% is irrigated. Two main crop seasons, “kharif” or monsoon (July-October) and "rabi" or post-monsoon (November-March), provide almost all food grain production. The intra-regional variability in climate change induced by greenhouse warming together with the inter-regional heterogeneities due to differences in spatial factors (soils, topography, length of crop growing season, major rainfed crops in a given area, runoff harvesting possibilities, ground water potential) might make the picture more complicated. When considering the increasing demand for water for various activities, it also becomes essential to know with sufficient accuracy the future availability of water, considering the probable effects of climate change, so as to plan and manage the resources and requirements.

There is an urgent need to view the various projected climate change scenarios in a balanced way. An accurate appraisal of the of the water resources of India is therefore of the utmost importance for the planning, development and utilization of water. A focused and careful examination of the different components of the prevailing agricultural systems in different regions should be done in order to provide options for adapting to climate changes.

Global climate change and hydrological impacts

Many attempts have been made to determine the trend in the mean temperature observations over land (Diaz & Quayle, 1980; Jones et al., 1982, 1986; Vinnikov et al., 1980; Hansen et al., 1981). The increase over recent years in greenhouse gases in the atmosphere has resulted in enhancing the greenhouse effect and thus global warming. The average global near-surface air temperature has increased by about 0.5 ^{o}C since the late 19th century (Jones et al., 1986; WMO, 1987), which is roughly consistent with simulation results based on CO_2 warming (Hansen et al., 1981). The striking feature, however, is that the inter-annual variability of global temperature is much larger than the trend. Current evaluations of the effects of human activities on global climate are based almost entirely on results from General Circulation Models (GCMs). According to the IPCC business – as – usual (BAU) scenario (scenario A), it is expected that the average global surface temperature may rise by 0.2 to 0.5 ^{o}C per decade during the future if human activities which cause greenhouse gas emissions continue unabated (IPCC, 1990).

Hydrological impacts

Many studies of the hydrological impacts of climate change have been carried out in different parts of the world by many workers. Studies on changes in annual and seasonal runoff have pointed to a great sensitivity of river basins even to insignificant changes in climatic characteristics, especially for basins located in arid and semiarid regions (Lins et al., 1990). Over the last two decades, a period of progressive desiccation has been noted over the Sahel and in Sudan. The available evidence supports the view that the Sahelian drought is an aspect of climate variability.

The possible impacts of climate change on the hydrological regime include: increase in summer evaporation, more rainstorms caused by increased convective precipitation in the summer months, increased intensity of tropical storms and increased monsoon rainfall in the tropics (IPCC, 1990).

Climate change and trends over india

In India, accurate climate data are available only for the past hundred years (Chowdhury & Ganesan, 1981; Prasad & Gadgil, 1986). Several studies of climate variability on both short and long time scales have been carried out in India and abroad to establish climate changes over India. Two major groups, at the Indian Meteorological Department and at the Indian Institute of Tropical Meteorology, have mainly dealt with the analysis of long-term temperature and precipitation records (Sarker & Thapliyal, 1988). Most of the studies of temperature analysis dealt with the analysis of surface temperature records of some individual observatory stations in the country; very few studies have been made of surface temperature trends in the country as a whole (Pramanik & Jagannathan, 1954; Jagannathan, 1963; Jagannathan & Parthasarathy, 1972; Hingane et al., 1985).

The mean annual temperature over India during the period 1901-1982 is shown in Fig. 1 (Hingane et al., 1985). The trend line indicates about 0.4 ^{o}C warming during the recent eight decades. This warming is mainly caused by the post-monsoon and winter seasons and is found to be pronounced for the west coast, the interior peninsula and the north-central and northeast regions of the country. The steady increase in the mean annual temperature for India is in contrast to the post-1940 cooling observed for the northern hemisphere. Although the results cannot be expressed in terms of cause and effect, a significant increase in the consumption of fossil fuel, deforestation and land use during the period can be noted.

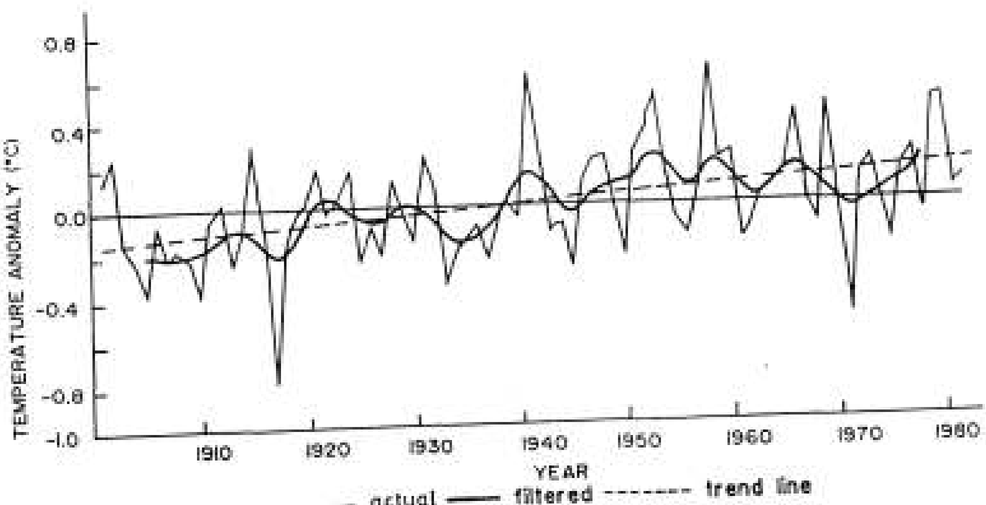

Fig. 1 Mean annual temperature anomalies in India during the period 1901-1982: actual, filtered and trend line (Hingane *et al.*, 1985).

The precipitation patterns over India have been intensively studied over the years beginning from 1886 (Blanford, 1886; Walker, 1910, 1914, 1922) with the studies mainly centered on the prediction of monsoon rainfall. Rao (1936), Agarwala (1952), Pramanik & Jagannathan (1953) and Rao & Jagannathan (1963) analysed 40-100 years of rainfall data from different Indian stations and concluded that there was no major climate change in the rainfall series. Further detailed analysis of rainfall data has been done by several investigators (Koteswaram & Alvi, 1969, 1970; Parthasarathy & Dhar, 1974; Raghavendra, 1973, 1974, 1976, 1980; Parthasarathy, 1984) in different regions or subdivisions of India and no long term trend in the rainfall data was detected. Mooley & Parthasarathy (1984), Rajagopalachari et al. (1984) and recently Thapliyal & Kulshreshtha (1991) have carried out detailed examinations of the series to determine the trend in annual rainfall over India (Fig. 2).

They all found that five-year running mean has fluctuated from the normal rainfall within ± one standard deviation. They did not find any long term climate change and trend.

Very little work on long term pressure changes has been done in India. Pramanik & Jagannathan (1955) studied the mean sea level annual pressure at 25 observatories over India. They did not find any systematic trend in the pressure.

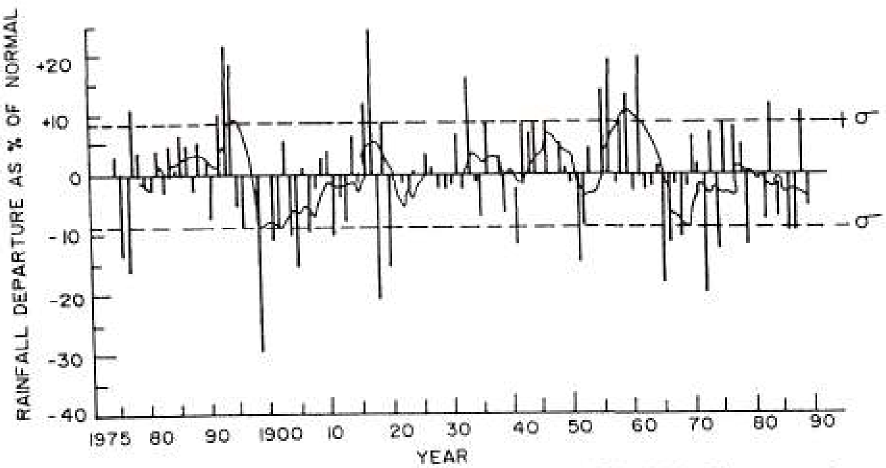

Fig. 2 Annual rainfall in India for the period 1875-1989. The curve shows the 5-year running mean; the dotted lines indicate the upper and lower limits ± one standard deviation (Thapliyal & Kulshreshtha, 1991).

The above studies mainly concentrated on the long term analysis of temperature and rainfall data. In recent decades, pressure and rainfall have not shown any systematic trend. However, temperature has shown slight warming over India. Work on the expected climate change in India due to enhanced greenhouse effects, as revealed by global climate models, started recently with studies by Lal & his co-workers (1992,1993a, 1993b).

India's contribution to global warming

The contribution to greenhouse effects from India have been reported to be only about 4% and sue to agricultural practices, biomass burning, power generation from coal-based thermal plants, transportation and deforestation (Hai et al., 1990).

The emission of carbon dioxide in India has increased from around 20 million metric tons of carbon (MMTC) in 1950 to above 175 MMTC in 1988 at the rate of about 5.6% per year (SenRoy & Prasad, 1991). The production of CFC in India, which was about 3000 metric tons in 1985, is expected to be no more than 12000 tons by 2000 AD, considerably less than the limits set by the Montreal Protocol (Mitra, 1989).

Impacts of climate change over India

Hydrology and water resources

As the problem of global warming and its impacts has received considerable attention globally, some work in this direction has also been recently initiated in India.

Groisman & Kovyneva (1989) assessed the impacts of climate change on Indian hydrology by using a set of statistical for the parameters describing the relationship between changes in global climate variables and those in local climate characteristics for different seasons of the year. They used annual mean surface air temperature average over the extra-tropical zone of the northern hemisphere as a global variable. They observed that an increase in mean annual surface air temperature has resulted in increasing precipitation totals over the whole of India, especially along the western coast of the subcontinent.

Based upon the results from high resolution general circulation models, the IPCC (1990) reports for the Indian sub-continent state that by 2030 on BAU scenarios (if few or no steps are taken to limit greenhouse gas emissions) " the warming varies from 1-2 ^{o}C throughout the year. Precipitation changes little in winter and generally increases throughout the region by 5-15 % in summer. Summer soil moisture increases by 5-10 %".

Lal et al. (1992) studied the impact of increasing greenhouse gas concentrations on the climate of the Indian subcontinent and its variability by analyzing the GCM output data of the Hamburg global coupled atmosphere ocean circulation model with a resolution of 300 X 300 km^2 . The model results obtained from the greenhouse warming experiment suggested an increase of over 2 ^{o} K over the monsoon region in the next 100 years. The model simulated an increase in total (average for the study area) seasonal precipitation (Fig. 3). However, any significant precipitation change could only be isolated over some areas. Lal et al. (1992) did not find any evidence for a significant change in the mean monsoon onset data or in its inter-annual variability in a warmer world. Lal & Chander (1993b) have assessed that an enhanced surface warming over the Indian subcontinent by the end of the next century would result in more runoff in the

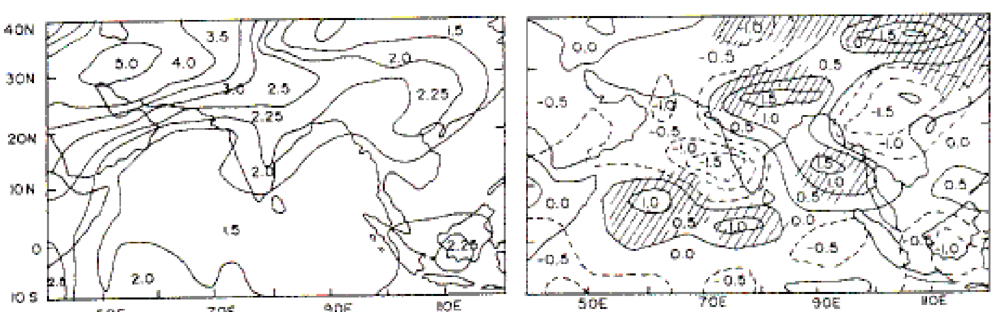

Fig. 3 Spatial distribution of changes in: (a) temperature: and (b) rainfall for the Indian subcontinent as simulated by the Hamburg coupled climate model under the business as usual scenario. The hatched area represents significant changes at the 90% level (Lal *et al.*, 1992).

northeast and central plains during the monsoon, with no substantial change during the winter season (Fig. 4). The results, however, are not statistically significant.

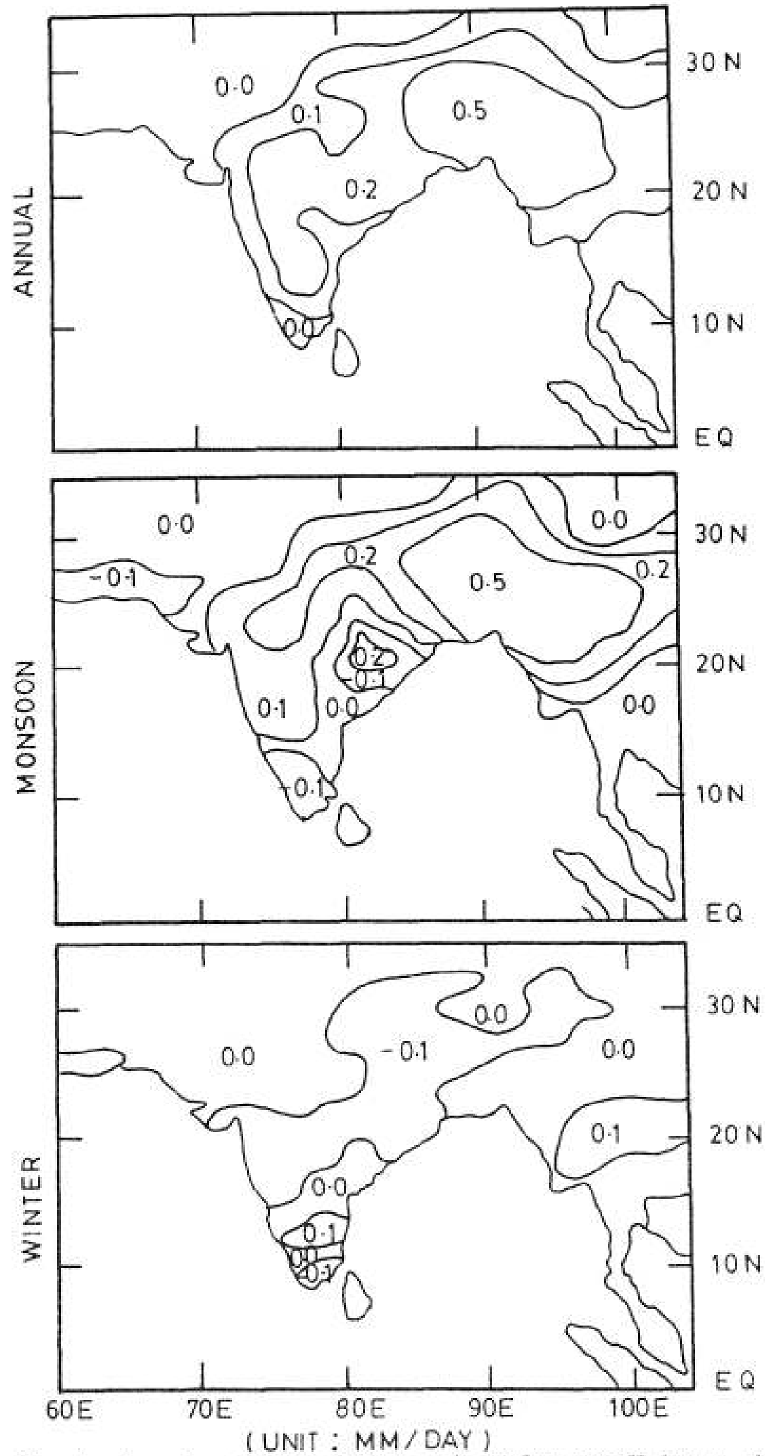

Fig. 4 Annual and seasonal changes in surface runoff due to global warming for the Indian subcontinent as simulated by the ECHAM3 T-42 model (Lal & Chander, 1993).

Using the above model, Lal & Bhaskaran (1993a) examined the possible changes in the climate of northwest India (Thar Desert) due to greenhouse warming. The results pointed to a pronounced warming and associated enhancement in the evaporation rate without any significant change in the precipitation over the region over the next 100 years. This may lead to an enhanced aridity over the Thar Desert and could have major implications for the hydrology and water resources in this region.

Divya & Jain (1993) carried out a sensitivity analysis of the response of a catchment situated in central India to expected climate changes using several scenarios of climate change and a regional model. The changes in runoff were more dramatic for the months when the runoff was already very small.

Since the results of a study for one catchment cannot be directly applied to other catchment, further similar studies were undertaken (Mehrotra & Divya, 1994a, 1994b, 1994c). the regional effects of climate change due to greenhouse warming on various components of the hydrological cycle were examined viz surface runoff, soil moisture and evapotranspiration(ET), using a conceptual model on a monthly basis and plausible hypothetical scenarios of precipitation and temperature changes for three drainage basins in different agroclimatic zones in central India. A sensitivity analysis indicated that basins located in comparatively drier regions are more sensitive to climate changes. Also, basin characteristics such as soil type, moisture holding capacity and runoff coefficient play an important role in deciding the basin response. To study the effect of climate variations on the design and operation of water resources projects, the response of the hypothetical reservoirs of two drainage basins of India to climate variations was studied (Mahrotra et al., 1994). Series of streamflows under different adopted climate variations were derived and used in modeling the influences of these variation on reservoir storage. The results of the study indicated a high probability of significant effects of climate change on reservoir storage.

Sea level rise

The studies of the ecosystem in coastal regions have pointed out that some of the coastal regions of Indian subcontinent are vulnerable to sea level rise (Ahmed & Sengupta, 1984). Conclusions on the implications of sea level rise in India, as made during a workshop organized by National Institute of Oceanography (NIO, 1988), are:

(a) low-lying coral atolls of the Lakshadweep archipelago are the regions most vulnerable to sea level rise.

(b) The Indian east coast, with a larger frequency of storms and lower continental slopes, is more vulnerable to storm surges and coastal flooding than the west coast.

(c) On the west coast, the stretch between approximately 12 and 18 ^{o}N is the least vulnerable; the coastline to the south of this belt has shown a tendency for erosion and denudation, which are likely to increase with sea level rise.

Agriculture

The impacts of enhanced greenhouse effects on crops would be through the direct effect of increasing CO_2 levels on crops, the direct effects of greenhouse gases other than CO_2, the effects of increasing temperature and precipitation or combinations of any of these three. Studies in the past have shown that increasing levels of carbon dioxide could increase photosynthesis rates and hence dry matter production.

Cereals such as rice (the major crop in "kharif") and wheat (the major crop in "rabi") are the major food grains for consumption in India and are sensitive to high temperatures (Sinha et al., 1989; Sinha & Swaminathan, 1991). Sinha (1989) reported that, assuming an increase in temperature by 2 °C, a decrease in yield of rice in the western parts of the country is expected to be 0.75 ton ha^{-1} , whereas in coastal areas where yields in the "kharif" are poor, it would be about 0.04-0.08 ton ha^{-1} . The productivity of wheat would also be affected adversely due to a temperature rise. A reduction of 0.45 ton ha^{-1} could be expected for each 0.5 ^{o}C increase in temperature. Thus, an increase of 0.5 ^{o}C in the mean temperature in western India would reduce productivity by 10%, while in central India, where the productivity is somewhat lower. The decrease might be lower.

Singh et al. (1991), however, found results somewhat opposite when considering the combined effect of changes in temperature and precipitation together with CO_2 enrichment. They argued that the adverse effects of a 1-2 ^{o}C rise in temperature could be absorbed with the 5-10% increase in precipitation, and for a doubling of CO_2 concentration, the yield might increase by 20-30% over about 70% of the area under rice and wheat. The results, however, aimed only to review the probable impact of CO_2 enrichment and climate change on the productivity of important field crops grown in India and need further research.

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