Training Course

Climate Change and its Impact on Water Resources

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LECTURE - 1

INTRODUCTION TO CLIMATE CHANGE

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INTRODUCTION TO CLIMATE CHANGE

1. INTRODUCTION

Climate of region represents the long-term average of weather (more than thirty years). It is a resultant of extremely complex system consisting of different meteorological variables, which vary with time. Climate in a narrow sense is defined as "average weather", or more rigorously, as the statistical description in terms of mean and variability of relevant quantities of weather parameters over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by WMO. These parameters are most often surface variables such as temperature, precipitation and wind.

The climate change is a very common word in the present day world. The common man, media and scientists all seem to be concerned with this phenomenon. It is generally because the mean global temperature of earth is showing an increasing trend. However, this might not be true in a regional scale, but enough evidences have been gathered showing this increasing trend of temperature. The important evidences include worldwide retreat of glaciers in all latitudes, rising of the mean sea level, breaking of Antarctic ice sheets etc. Such changes may have severe impact on mankind and all other living species. Such scenarios of projection have urged researchers from all over the world and of all fields of science to study the problem in a greater depth.

Climate change refers to a statistically significant variation in either the mean state of the climate or in other statistics (such as standard deviations, the occurrence of extremes, etc.), persisting for an extended period particularly decades or longer. Climate change may be due to natural internal processes or external forcings, or to anthropogenic changes in the composition of the atmosphere or in the land use. Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that of UNFCCC which defines climate change as, "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". Climate change is not only a major global environmental problem, but also an issue of great concern to a developing country like India.

The earth's atmosphere - the layer of air that surrounds the earth - contains many gases. Short-wave radiation from the sun passes through the earth's atmosphere. Partly this radiation is reflected back into space, absorbed by the atmosphere and remainder reaches the earth's surface, where it is either reflected or absorbed. In turn the earth's surface, emits long-wave radiation toward space. The greenhouse gases (GHGs) available in the atmosphere principally include carbon dioxide (CO_2), nitrous oxide (NO_2), methane (CH_4), and chlorofluorocarbons (CFCs) and ozone (O_3). These GHGs absorb some of this long-wave radiation emitted by the Earth's surface and re-radiate it back to the surface. Ever since the industrial revolution began about 150 years ago, human activities have added significant quantities of GHGs to the atmosphere. An increase in the levels of GHGs could lead to greater warming which, in turn, could have major impact on the world's climate, leading to accelerated climate change. Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased from 280 ppm to 379 ppm, 715 ppb to 1774 ppb and 270 ppb to 319 ppb respectively, between pre-industrial period and 2005 (IPCC, 2007). Thus GHGs modify the heat balance of the Earth by retaining long-wave radiation that would otherwise be dispersed through the Earth's atmosphere to space. This effect is known as the greenhouse effect. Evidently, GHG have an important role in controlling the temperature of the earth and an increase in their concentration in the atmosphere would increase the temperature of the Earth. In addition, presence of excess quantities of CFCs affects the protective ozone layer which deflects the harmful short wave rays.

Global warming arising from the anthropogenic-driven emissions of greenhouse gases has emerged as one of the most important environmental issues ever to confront humanity in last two decades. Concern over global climatic changes caused by growing atmospheric concentrations of carbon dioxide and other trace gases has increased in recent years as our understanding of atmospheric dynamics and global climate systems has improved. Scientists have learnt a great deal in recent decades about the climate and its response to the human activities, particularly emission of the greenhouse gases such as carbon dioxide, methane, nitrous oxide etc. Nevertheless the global climate system is so vast and complex that it is difficult to understand very accurately. Consequently, some uncertainty remains in the outcome of the analysis. There is focus on scientific research along with probable impact on society. This problem is inextricably linked to the process of development and economic growth itself. This concern arises from the fact that our everyday activities may be leading to changes in the earth's atmosphere that have the potential to significantly alter the planet's heat and radiation balance. It could lead to a warmer climate in the next century, which may have adverse effect on the resources and society.

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. With climate change, there would be increasing scarcity of water, reduction in yields of forest biomass, and increased risk to human health. India released its National Action Plan on Climate Change (NAPCC) on 30th June, 2008 to outline its strategy to meet the Climate Change challenge. The National Action Plan advocates a strategy that promotes, firstly, the adaptation to Climate Change and secondly, further enhancement of the ecological sustainability of India's development path. India's National Action Plan stresses that maintaining a high growth rate is essential for increasing the living standards of the vast majority of people of India and reducing their vulnerability to the impacts of climate change. Accordingly, the Action Plan identifies measures that promote the objectives of sustainable development of India while also yielding to benefits for addressing climate change. Eight National Missions, which form the core of the National Action Plan, represent multi-pronged, long term and integrated strategies for achieving key goals in the context of climate change. The focus is on promoting understanding of Climate Change, adaptation and mitigation, energy efficiency and natural resource conservation.

2. GLOBAL CLIMATE CHANGE OVER LAST CENTURY

Concentrations of CO_2 and other trace gases in the atmosphere have increased substantially over the last century. Anthropogenic CO_2 emissions due to human activities are virtually certain to be the dominant factor causing the observed global warming. There are a number of studies to show the increase in temperature particularly since pre-industrial era. Recently, IPCC (2007) has indicated that the average global surface air temperature has increased by 0.74±0.18° C since the late 19th century. The linear warming trend over the last 50 years (0.13[0.10 to 0.16]° C per decade) is nearly twice that for the 100 years previous to that. The rate and duration of warming of 20th century has been found to be larger than any other time during the last 1000 years. Fig. 1 shows the trend of changes in globally average temperature over the last century. Temperature changes have not been uniform globally but have varied over regions and different parts of the lower atmosphere. The Diurnal surface temperature range (DTR) has not changed from 1979 to 2004 as both day and night time temperatures have risen at about the same rate. Hot days/ heat index increased, while cold/ frost days decreased for nearly all land areas during 20th century. Continental precipitation increased by 5-10% over the 20th century in the Northern Hemisphere although decreased in some regions (e.g., north and west Africa, parts of Mediterranean).

It is observed that the extent of snow cover on the global scale has decreased by 10% since late 1960s. A widespread retreat of mountain glaciers has been observed in non-polar regions during the 20th century. Further, it is expected that glaciers and ice caps will continue to retreat during the 21st century. Climatic changes had a pronounced effect on the glacial and periglacial regime of the Alps. Since the middle of the past century, the areal extent of glaciations in the European Alps is reduced by 30-40%, whereas the volume of ice has been reported to be reduced by 50%. It has been reported that existing trend of changes in the volume of glaciers shows that melting of glaciers will accelerate in continental regions, North America, South America, Central Asia, sub-polar glaciers will contribute to sea level rise. The global mean sea level has risen between 0.10 m to 0.20 m during the 20th century.

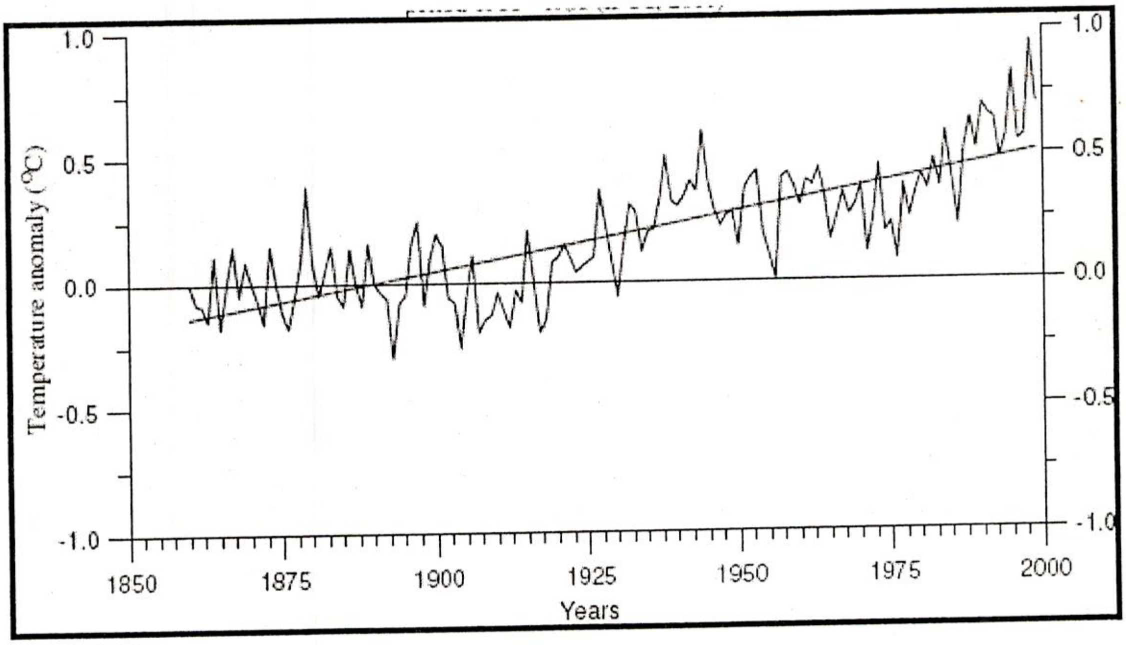

Fig 1: Observed rise in global mean temperature since 1860 relative to the average of observations over the period 1900 - 1930 (IPCC, 2001)

The apparent accelerated melting and deglaciation of the world's glaciers is considered as an indication of human-induced global warming and climate change. The areal extent of Arctic Sea ice has decreased by 2.7% per decade, with larger decrease in summer of 7.4% per decade. Studies also suggest further thinning of sea ice in the Arctic region. Moreover, permafrost and sea-ice extent are projected to decrease. Duration of ice cover of rivers and lakes decreased by about 2 weeks over 20th century in mid- and high latitude of the Northern Hemisphere. Greenland ice sheet is likely to lose mass during 21st century and contribute to the rise of sea level by few cm. Global models indicate that the local warming over Greenland is likely to be one to three times the global average. Antarctica ice sheet is likely to increase in mass during 21st century, but after sustained warming the ice sheet could lose significant mass and can contribute to sea level rise over next 1000 years. Global average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003. The total rise in 20th century is estimated to be 0.17 m.

3. FUTURE PROJECTIONS OF GLOBAL CLIMATE

Scenarios of future climate change are usually developed using the GCMs with different scenarios of GHG emissions. GCMs are complex 3-dimensional models of the land, atmosphere and oceans. However, in spite of some degree of confidence in the gross or aggregate estimates for climate parameters (such as globally averaged surface temperature) from these models, there is a great deal of uncertainty with regard to regional details. One of the weaknesses of GCM climate change predictions is that they cannot adequately resolve factors that might influence regional climates, such as the local effects of mountains, coastlines, lakes, vegetation boundaries, and heterogeneous soils etc.

For the next two decades a warming of about 0.2° C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all GHG and aerosols are kept constant at year 2000 levels, a further warming of about 0.1° C per decade could be expected. Under different GHG emission scenarios, the global averaged surface temperature is projected to increase by 1.4 to 5.8° C over a period of 1990 to 2100. The low-emission scenarios project the range of increase in temperature between 1.1 – 2.9° C, while high-emission scenarios project between 2.4 – 6.4° C. The striking feature is that the inter-annual variability of global temperature is much larger than the trend. According to simulations of global climate, it is very likely that nearly all land areas will warm more rapidly than the global average, particularly those at northern high latitudes during winter. In contrast, in south Asia and southeast Asia warming is projected to be relatively less than the global mean warming during summer and in southern South America in winter. The global mean sea level has been projected to rise by 0.09 m to 0.88 m between 1990 and 2100, which is much higher than the range (0.10 - 0.20 m) observed during 20th century. For each degree Celsius warming, global average precipitation is projected to increase by 2-4%, but at the regional scale both increases and decreases are projected. Global climate modelling studies suggest that the precipitation may increase or decrease by as much as 15% under the assumption of a doubling of atmospheric CO_2. Increases in the amount of precipitation are very likely in high latitudes, while decreases are likely in most subtropical land regions.

Based on the global simulations of the climate for a wide range of scenarios, global average water vapour concentrations and precipitation are projected to increase during the 21st

century. By the second half of the 21st century, precipitation will increase over northern mid to high latitudes. Increase in precipitation is also projected over Antarctica. At low latitudes there are both regional increases and decreases over land areas. Larger year to year variations in precipitation are expected over most areas where an increase in mean precipitation is expected. During 21st century snow cover and sea-ice extent in the Northern hemisphere are projected to decrease further and widespread retreat of glaciers and ice caps will continue. It is likely that Antarctica will gain mass due to higher precipitation in that region, whereas Greenland ice sheet is likely to lose mass because increase in runoff will exceed the increase in precipitation.

4. TRENDS OF CLIMATE CHANGE IN INDIA

4.1 Temperature

In India several studies have been carried out to determine the changes in temperature and rainfall and its association with climate change. However, investigators have used different data length and now studies have been reported using more than a century data. All such studies have shown warming trend on the country scale. An analysis of the seasonal and annual air temperatures from 1881 to 1997 shows that there has been an increasing trend of mean annual temperature by the rate of 0.57°C per 100 years. Trend of all India mean annual surface air temperature anomalies is shown in Fig. 2. The trend and magnitude of global warming over India/Indian sub-continent over last century has been observed to be broadly consistent with the global trend and magnitude. In India, warming is found to be mainly contributed by the post-monsoon and winter seasons. The monsoon temperatures do not show a significant trend in any part of country except for significant negative trend over Northwest India.

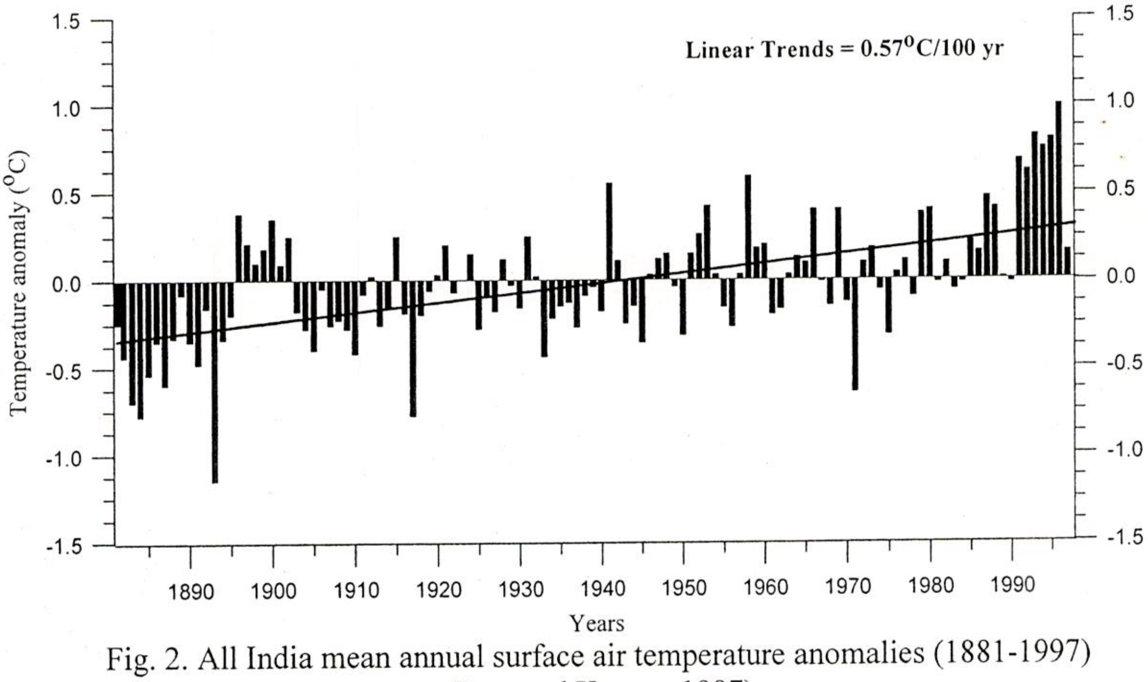

Fig. 2. All India mean annual surface air temperature anomalies (1881-1997) (Pant and Kumar, 1997)

An investigation carried out to identify trends in temperature time series of 125 stations distributed over the whole of India indicated that annual mean temperature, mean maximum temperature and mean minimum temperature have increased at the rate of 0.42, 0.92 and 0.09°C $(100 \text{ year})^{-1}$, respectively. On a regional basis, stations of southern and western India show a rising trend of 1.06 and 0.36°C $(100 \text{ year})^{-1}$, respectively, while stations of the north Indian plains show a falling trend of –0.38°C $(100 \text{ year})^{-1}$. The seasonal mean temperature has increased by 0.94°C $(100 \text{ year})^{-1}$ for the post-monsoon season and by 1.1°C $(100 \text{ year})^{-1}$ for the winter season.

Analysis of seasonal and annual trends of changes in maximum temperature (T_{max}), minimum temperature (T_{min}), mean temperature (T_{mean}), temperature range (T_{range}), highest maximum temperature (H_{max}) and lowest minimum temperature (L_{min}) over the last century covering 9 river basins in northwest and central part of India showed that majority of basins (7 river basins: Ganga, Indus-lower, Mahanadi, Mahi, Narmada, Brahamani & Subaranrekha, and Tapi) have shown increasing trend in mean annual temperature in the range of 0.40 to 0.64 °C per 100 years, while 2 basins (Sabarmati and Luni & other small rivers) have shown cooling trend varying between –0.15 to -0.44 °C per 100 years. The Narmada river basin has experienced maximum warming and Sabarmati river basin has shown highest cooling trend. For the whole study area, the maximum temperature has shown increasing trend of 0.81°C/100 years. The rate of increase of T_{max} was observed to be higher than that of T_{min} in this study area. Both H_{max} and L_{min} have shown increasing trend in the study area. Results of the seasonal analysis show that maximum increase in T_{max} and T_{mean} was observed in the post-monsoon season, whereas T_{min} experienced the largest variation in the monsoon season. Except Narmada and Mahi basins, all other basins have shown increasing trend of T_{range}. The present study shows that for the study area the largest variation in T_{range} (0.93°C/100) was observed in the monsoon season. However, for this season, increase in T_{max} and decrease in T_{min} cancelled out the trends in T_{mean} providing the least variations in T_{mean}.

4.2 Rainfall

Studies related to changes in rainfall over India have shown that there is no clear trend of increase or decrease in average annual rainfall over the country. The examination of trend of annual rainfall over India has indicated that 5 year running mean has fluctuated from normal rainfall within ± one standard deviation. Summer monsoon rainfall anomalies for all India are shown in Fig. 3. Though the monsoon rainfall in India is found to be trendless over a long period of time, particularly on the all India scale, but there are pockets of significant long-term rainfall changes.

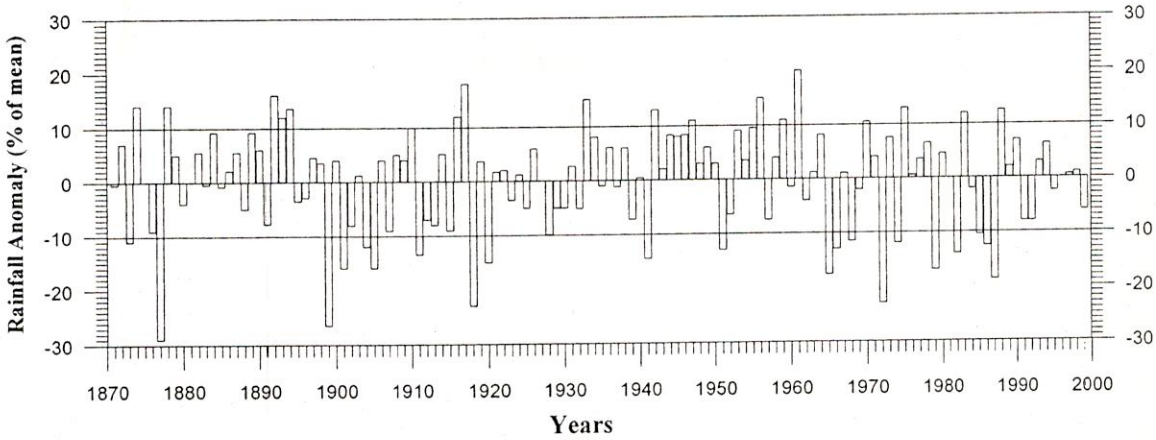

Fig. 3: All India summer monsoon rainfall anomalies (1871-1999) (Lal, 2001)

A comprehensive study using the monthly rainfall data for 306 stations distributed over India showed that areas of north-east peninsula, north-east India and north-west peninsula indicate widespread decreasing trend in the Indian summer monsoon rainfall. On the other hand, a widespread increasing trend in monsoon rainfall over the west coast, central peninsula and north-west India was found. The decreasing trend ranges between -6 to -8% of the normal per 100 years while the increasing trend is about 10 to 12% of the normal per 100 years. Though these trends are statistically significant, but they account for a relatively small part of the total variance in the rainfall.

Trend analysis carried out on sub-divisional rainfall data of 135 years (1871-2005) indicated no significant trend for annual, seasonal and for any monthly rainfall on all-India basis. Annual and monsoon rainfall decreased and pre-monsoon, post-monsoon and winter rainfall increased over the years, with maximum increase in pre-monsoon season. Further analysis on sub-divisional basis (30 sub-divisions) indicated that half of the sub-divisions have shown increasing trend in annual rainfall whereas remaining half sub-divisions showed decreasing trend in annual rainfall.

Trend and variability of seasonal and annual rainfall on the basin scale for the northwest and central parts of India showed that all the nine studied basins except Mahanadi have shown increasing trend in mean annual rainfall ranging from 2-19% of mean per 100 years. The Indus (lower) basin experienced maximum increase (19%). Ganga, Sabarmati and Brahamani and Subarnarekha river basins have experienced stable annual rainfall. For the whole northwest and central India, the annual rainfall has increased by 5.2% of mean per 100 years. Seasonal rainfall analysis showed that maximum increase in rainfall was observed in the post-monsoon season followed by the pre-monsoon season. The monsoon rainfall has shown least variations over the last century. Annual rainy days decreased for all the river basins, except Indus (lower), while the magnitude of heaviest rain has increased for all the basins in the range of 9 to 27 mm per 100 year. Brahmaputra basin showed a decreasing trend, Meghna river basin showed increasing trend and Ganga river basin showed no change in annual rainfall during the period 1951-2004 (Kumar and Jain, 2009a). Monsoon rainfall was found to have increased over Brahmaputra and Meghna and decreased over Ganga basin. Rainfall increased over Ganga and Meghna basins in pre-monsoon season and over Meghna in post-monsoon season. The winter rainfall was found to have increased over all the three river basins. None of the increasing or decreasing trend is found significant at 95% confidence level.

6.0 FUTURE CLIMATIC SCENARIOS FOR INDIA

Future warming scenarios have been generated for the Indian sub-continent using GCM. Lal (2001) developed climate change scenarios over Indian sub-continent under the four SRES based on the data generated in numerical experiments with Atmosphere and Ocean coupled GCM of the CCSR/NIES, Japan to predict changes in temperature and temporal and spatial variability of the monsoon rainfall. Future projection of increase in temperature and changes in precipitation over Indian subcontinent are shown in Table 1.

It is projected that over the inland regions of the Indian sub-continent, the mean surface temperature may rise between 3.5° C and 5.5° C by 2080. On seasonal basis, the projected surface warming is higher in winter than during summer monsoon. The spatial pattern of temperature change has a large seasonal dependency. The spatial distribution of surface warming suggests that north India may experience an annual mean surface warming of 3° C or more by 2050s. GCM models have simulated peak warming of 3° C over north and central India in winter. Over much of the southern peninsula, the warming is likely to be under 2° C during winter season. The surface temperature rise would be more pronounced over northern and eastern region (~2° C) during the monsoon season.

The increase in annual mean precipitation over the Indian sub-continent is projected to be 7 to 10% by 2080s. Winter precipitation may decrease by 5 to 25% in the Indian sub-continent. An increase of 10 to 15% is projected in areaaverage summer monsoon rainfall over the Indian sub-continent. Over northwest India, during monsoon season an increase of about 30% or more is suggested by 2050s. The western semiarid margins of India could receive higher than normal rainfall in the warmer atmosphere. It is likely that date of onset of summer monsoon over India could become more variable in future. IPCC (2001) has indicated that variability in Asian summer monsoon is expected to increase along with changes in the frequency and intensity of extreme climate events in this region. All climate models simulate an enhanced hydrological cycle and increases in annual mean rainfall over South Asia (under non-aerosol forcing).

Table - 1 Climate change projections for the Indian sub-continent

Scenarios		Increase in temperature (°C)	Change in rainfall (%)
2020s	Annual	1.00 – 1.41	2.16 – 5.97
	Winter	1.08 – 1.54	(-)1.95 – 4.36
	Monsoon	0.87 – 1.17	1.81 – 5.10
2050s	Annual	2.23 – 2.27	5.36 – 9.34
	Winter	2.54 – 3.18	(-)9.22 – 3.82
	Monsoon	1.81 – 2.37	7.18 – 10.52
2080s	Annual	3.53 – 5.55	7.48 – 9.90
	Winter	4.14 – 6.31	(-)24.83 – 4.50
	Monsoon	2.91 – 4.62	10.10 – 15.18

The latest high resolution climate change scenarios and projections for India, based on Regional Climate Modelling (RCM) system, known as PRECIS developed by Hadley Center and applied for India using IPCC scenarios A2 and B2 depicts the following:

- An annual mean surface temperature rise by the end of this century, ranging from 3°C to 5°C (under A2 scenario) and 2.5°C to 4°C (under B2 scenario), with the warming more pronounced in the northern parts of India.
- A 20 per cent rise in all India summer monsoon rainfall and a further rise in rainfall is projected over all states except Punjab, Rajasthan and Tamil Nadu, which show a slight decrease.
- Extreme rise in maximum and minimum temperatures is also expected and similarly extreme precipitation is also projected, particularly over the West Coast of India and West Central India.

7. IMPACT OF CLIMATE CHANGE ON INDIAN WATER RESOURCES

Availability of numerous water bodies and perennial rivers systems makes Indian sub-continent one of the wettest places in the world after South America. In India, large Himalayan Rivers including Indus, Ganga and Brahmaputra are perennial sources of fresh water though the flow is reduced during non-monsoon periods. The south peninsular are solely dependent 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 into India river systems. The impact of future climatic change is expected to be more severe in developing countries such as India whose economy is largely dependent on the agriculture and is already under stress due to population increase and associated demands for energy, fresh water and food. The physical impacts of climate change are coupled with societal issues and management practices. The status of studies shows that the possible impacts of climatic changes on various aspects of hydrological cycle are not much studied in India.

Water resources are sensitive to the climate change. Temperature drives the hydrological cycle, influencing hydrological processes in a direct or indirect way. A warmer climate may lead to intensification of the hydrological cycle, resulting in higher rates of evaporation and increase of liquid precipitation. These processes, in association with a shifting pattern of precipitation, may affect the spatial and temporal distribution of runoff, soil moisture, groundwater reserves etc. and may increase the frequency of droughts and floods. The future climatic change, though, will have its impact globally but likely to be felt severely in developing countries with agrarian economies, such as India. Surging population, increasing industrialization and associated demands for freshwater, food and energy would be areas of concern in the changing climate scenarios. Increase in extreme climatic events will be of great consequence owing to the high vulnerability of the region to these changes. Water resources will come under increasing pressure in the Indian subcontinent due to the changing climate.

The Himalayan region, called the "*Water Tower of Asia*", supports 9575 glaciers in India having an area of about 18000 km^2 and a volume of about 1300 km^3. The main river basins fed by glaciers are the Indus, the Ganga and the Brahmaputra. The importance of these river systems can be understood from the fact that these three river systems contribute more than

60% to the total annual runoff from all the rivers of India. These river systems hold immense potential as a future freshwater source and drain the major plains of the country. These major river systems consist of 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, reduction in solid precipitation in mountain regions would have direct impact of water resources affecting the drinking water, irrigation, hydropower generation and other applications 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.

The river systems of central, western and southern India are charged by groundwater and their flows are reinforced by the seasonal rainfall. The water potentials of these non- snow and glacier fed rivers are strongly associated with the conditions of monsoons. A poor monsoon rainfall leads to drought conditions and situation is further aggravated if monsoon fails for consecutive years and back-to-back drought occurs. Studies carried out on 12 river basins of India using SWAT model indicated that as a result of global warming, the conditions may deteriorate in terms of severity of droughts in some parts of the country and enhanced intensity of floods in other parts. A general overall reduction in the quantity of the available runoff is expected under the GHG scenario.

It is likely that the frequency of floods and droughts will increase during 21st century due to projected climate change, which would enhance the severity of water extreme events and may prove the greater challenge to society. Changes in the amount of rainfall, rainfall patterns and intensity would affect stream flow and the demand for water. According to country's report to the United Nations Framework Convention on Climate Change (UNFCCC), the global climate change is likely to result in severe droughts and floods in India - and have major impacts on human health and food supplies. 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 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 likely to bring more sediment and even dam failures. The design and management of both structural and non-structural water-resource systems should allow for the possible effects of climate change. It is clear that flood and drought management schemes have to be planned keeping in view the increase in severity of floods and droughts and expected changed climatic scenarios over the country. Despite these uncertainties, it is clear that even the possibility of changes in such extreme events is quite alarming.

Impact of climate changes on the ground water regime is also expected to be severe. It is to be pointed out that groundwater is the principle source of drinking water in the rural areas. About 85% of the rural water supply in India is dependent on groundwater. The projected climate change resulting in warming, sea level rise and melting of glaciers will adversely affect the water balance in different parts of India and quality of ground water along the coastal plains. Climate change is likely to affect ground water due to changes in precipitation and evapotranspiration. Rising sea levels may lead to increased saline intrusion into coastal and island aquifers, while increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. Increased rainfall intensity may lead to higher runoff and possibly reduced recharge.

The water resources of the country are likely to be affected due to climate change. The adaptation strategies have to be considered in the water resources sector in view of these changes. Studies are required to be taken up for developing the modified methodologies for the assessment of water resources, hydrological design practices, flood and drought management, operation policies for the existing as well as proposed water resources projects and assessment of available water for irrigation including the land uses and cropping patterns.

Most of the studies carried out for projecting futuristic scenarios of water resources for different basins are very preliminary. The consequences of changes in climate on Indian water resources are poorly understood. It is felt to standardize the regional future climatic scenarios on regional/basin scale. Using these scenarios, an assessment of water availability in different basins in the context of future requirements taking particular account of the multiplying demands for water is critical for resource planning and sustainable development as a basis for economic and social development has to be carried out.

Issues on climate change impact on water resources

1. 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.
2. Reliable downscaling of GCM (Global Circulation Model) projections to regional and basin level
3. Improvement required in hydro-meteorological network design for adaptation
4. Assessment of impact on surface and ground water interaction with specific emphasis on coastal areas
5. Impact of Climate Change on LandUse/LandCover and their coupled impact on water resources
6. Impact on Intensity-Duration-Frequency relationships in Urban Areas
7. Impact on magnitude-duration-frequency of drought (Agricultural, meteorological and hydrological)
8. Impact on sediment loads and their management implications

Issues on mitigation/adaptation measures

Some of the studies in this category may include

1. Updating the basin wise water availability
2. Coping with the variability in the water sector through development and regulation
3. Review of hydrological design and planning criteria under the changed scenario
4. Study of Water-Energy-Climate change relationships
5. Development of databases and associated tool-boxes for Integrated Water Resources Management (IWRM)

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