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Climate Change Implications on Water Resources in India-Review

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Abstract Several studies around the globe shows that chane in global surface temperature, rainfall, evaporation and extreme events since the start of 20th century. The studies ahowed that climatic change is likely to have a significant impact upon fresh water resources availability. The demand for water has already increased tremendously over the years due to an increasing population, expanding agriculture, rapid industrialization, urbanization and economic development. In this context, analyzing and forecasting climate change impacts on water requirement of horticulture crops is vital before devising suitable adaptation strategies and planning and management of limited water resources in arid and semi-arid region of country. An overview of the global warming and climate change, trends in increase in temperature and change in precipitation over Indian sub continent are compared with global trends. This paper also presents an overview of current water resources scenario in India, and recent work carried out in India to asses the climate change impact on water resources.

Keywords Climate change, Horticulture, Water resources.

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Introduction

India is bestowed with a varied agro-climate, which is highly favorable for growing a large number of horticultural crops such as fruits, vegetables, root tiber, aromatic and medicinal plants and spices and plantation crops like coconut, cashew and cocoa. Presently, horticultural crops occupy around 13% of India's gross cropped area. India is the second largest producer of fruits and vegetables. Hortiuculture sector contributes around 29.65% of GDP. There is now clear evidence for an observed increase in global average temperatures around the world since the start of the 20th century and there is clear evidence that climatic extreme events i.e. heavy rainfall/snowfall rates have changed during the 20th century (1). In India, studies by several authors have shown that there is increasing trend in surface temperature (2) and no significant trend in rainfall and decreasing/increasing trends in rainfall (3).

Water resources will come under increasing pressure in Indian subcontinent due to the chaging climate. These changes will have profound affects on water requirement of Horticulture crops in India The climate affects the demand for water as well as the supply and quality. Particularly, in arid and semi-arid regions of India nay shortfall in water supply multi-

Table 1. Water resources in India. Source (2).

Annual precipitation	4000 b.cu.m
Available water resources	1869
Utilizable	1122
Surface water (storage and diversion)	690
Ground water (replenishable)	432
Present utilization	605
(surface water 63% ground water 37%)	
Irrigation	501
Domestic	30
Industry energy and other uses	74

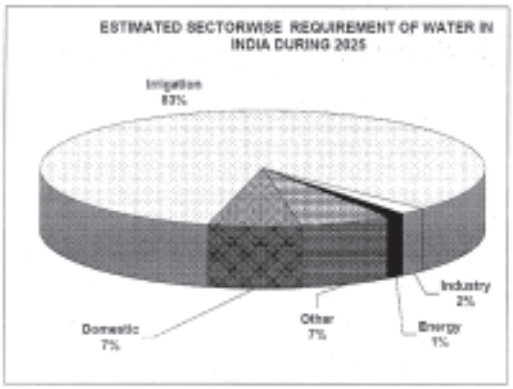

Fig. 1. Sector wise water requirement. (Source (34).

plied with climate change will enhance competition for water use for a wide range of economic, social and environmental applications. In the future scenarios, larger population will lead to heightened demand for irrigation. After 2025 AD climate could also make conditions worse of rainfall amounts decrease in the major food producing regions and evaporation rates increase. Urgent and decisive action must hegin now to avoid water crises during the next 30 years which will benefit horticulture and other crops.

In view of the above, an attempt was made to review to give brief resume of the status of water resources in India, possible impact of climate change on India's surface, groundwater resources and studies made on impact of climate change and identifying research needs, are discussed.

Water resources of India

Although India occupies only 3.29 million km^2 geographical area, which forms 2.4% of the world's land area, it supports over 15% of the world's population. The population of India as on 1 March 2001 stood at 1,027,015,247 persons. Thus, India supports about 1/6th of world population, 1/50th of world's land and 1/25th of world's water resources (4). The total utilizable water resources of the country (5) are assessed as 1086 km^3. A brief description of water resources of India is given in Table 1.

Ground water resources

The annual potential natural groundwater recharge from rainfall in India is about 342.43 km^3, which is 8.56% of total annual rainfall of the country. The annual potential groundwater recharge augmentation from canal irrigation system is about 89.46 km^3. Thus, total replenishable groundwater resource of the country is assessed as 431.89%. After allotting 15% of this quantity for drinking, and 6 km^3 for industrial purposes, the remaining can be utilized for irrigation purposes. Thus, the available groundwater (5) resource for irrigation is 361 km^3, of which utilizable quantity (90%) is 325 km^3.

Water requirements of India

At present, available statistics on water demand show that the agriculture sector is the largest consumer of water in India. About 83% of the available water is used for agriculture alone. The quantity of water required for agriculture has increased progressively through the years as more and more area was brought under irrigation. Since 1947, irrigated area in India rose from 22.60 Mha to 80.76 Mha upto June 1997. The contribution of surface and groundwater resources for irrigation has played a significant role in India attaining self-sufficiency in food production during the past 3 decades and is likely to become more critical in future in the context of national food security. According to available estimates, the demand on water in this sector is projected to decrease to about 68% by the year 2050 though agriculture will remain the largest consumer. In order to meet this demand, augmentation of existing water resources by development of additional sources of water or conservation of the existing resources through impounding more

Table 2. Climatic changes during 20th century. Source (21).

Region	Temperature	Rainfall	Reference
All-India	Increase in 0.4°C yrs in mean annual temperature		(14)
All-India	Increase in maximum temperature (0.6°C/100 yrs). Minimum temperature trend less. General increase in thediurnal range of temperature.		(15)
Indo-Gengetic Plain Region	Annual sirface air temperature of IGPR shows rising trend (0,53°C/100 yrs during 1875-1958). Decreasing trend (-0.93°C/100 yrs during 1958-1997)	Summer monsoon rainfall over western IGPR shows increasing trend (170 mm/100 y) from 1900, while over central IGPR it shoes decreasing trend (5 mm/100 y from 1939 and over eastern IGPR a decreasing trend (50 mm/100 y) during 1984-99. Westward shift in rainfall activities over the IGPR	(16)
All-India		Monsoon rainfall is trend less and is mainly random in nature over a long period	(17) (18)
Western and Eastern Himalayas		Western Himalayas gets more snowfall than eastern Himalayas during winter. More rainfall in the eastern Himalayan than in the western Himalayas during monsoon season	(19)
All-India		Decade departures in summer monsoon rainfall are found above and below the long-time average alternatively for three consecutive	(20, 21)

water in the existing water bodies and its conjunctive use eill be needed (2). Sector wise water requirement by 2025 is shown in Figure 1.

Observed climate changes and its impact during 20th century over India

Temperature and rainfall

Selective observed changes in temperature and rainfall over India during last century is shown in the Table 2. As per the reports shown in table confirm increase in temperature and change in rainfall pattern during 20th century.

Higher frequency of droughts: Because of the dominance of the monsoon, India's climate and weather exhibit the heaviest seasonal concentration of precipitation in the world. Almost 20% of India's total land area is drought prone. The frequency of droughts has been increasing over time. There were six droughts between 1900 and 1950 compared to 12 in the following 50 years, and 3 droughts have already occurred since the beginning of the 21st century. Escalating levels of ecological degradation, resulting from such

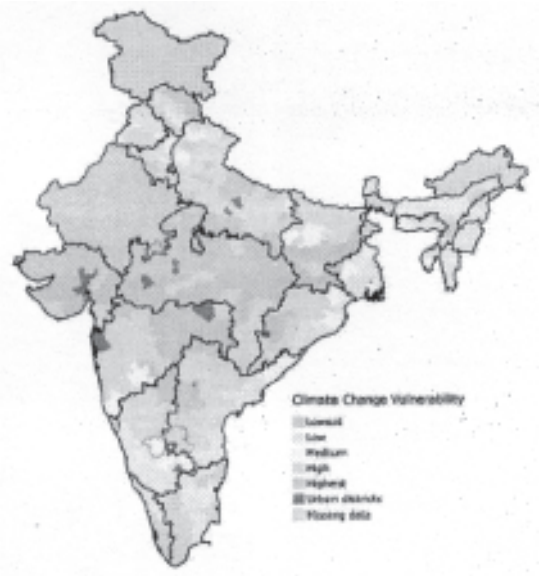

Fig. 2. District level mapping of climate change vulnerability, measured as a composite of adaptive capacity and climate sensitivity under exposure to climate change (Source 35).

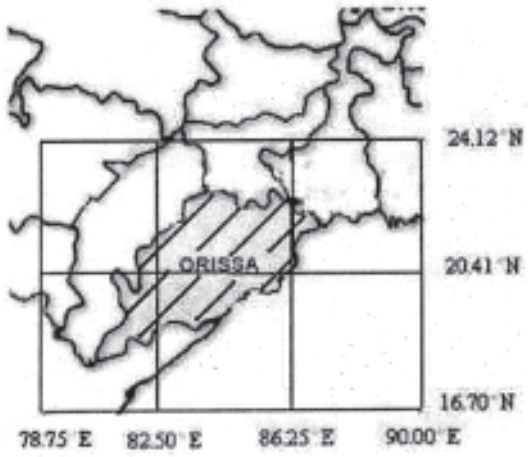

Fig. 3. GCM grids superposed on map of Orissa for down scaling. Source (13).

factors as deforestation, receding water tables and overgrazing have increased the vulnerability of ecosystems to drought. Figure 2 shows climate change vulnerability.

Sea-level rise: In 1991 a rising trend in sea level at Mumbai during 1940-86 and Chennal during 1910-33 was reported earlier (6), based on the annual means of tide-guage observations. In, 1993 the atmospheric tide-guage data studied earlier (7) and confirmed a rice in sea level by 8 cm.

Projections of future climate change

Table 3 shows selective reports about projected climate changes using global climate models (GCM) and Regional Climate Models (RCM) over India during 21st century. All report showed changing patterns in rainfall and in increase in temperature.

Projected climate impacts on water resources

Table 4 shows the selective reports on impact on water resources during next century over India. The enhanced surface warming over the Indian subcontinent by the end of the next century would result in an increase in pre-monsoonal and monsoonal rainfall and no substantial change in winter rainfall over the central plains. This would result in an increase in the monsoonal and annual runoff in the central plains with no substantial change in winter runoff. These studies also indicate an increase in evaporation and soil wetness during the monsoon and on an annual basis (8).

Studies on climate impact on water resources India

Studies have reviewed that an enhanced surface warning over the Indian subcontinent by the end of the next century would result in more runoff in the northeast and central plains during the monsoon, with no substantial change during the winter season. The possible changes in the climate of northwest India due to greenhouse warming has examined. It has been observed that an increasing precipitation totals over the whole of India, particularly along the western coast of the subcontinent (9).

A sensitivity analysis of the response of catchment which is in central India to expected climate changes using several scenarios of climatic change

Table 3. Projected climate change during next century over India. Source (2).

Region	Temperature	Rainfall	Reference
All-India	Increase in winter temperature by 104°C with increased CO_2 concentration	Precipitation increase of approximately 20% increase in heavy rainfall days during the summer monsoon period and on increased inter-annual variability	(22)
All-India	Average temperature change is predicted to be in the range of 2.33 to 4.78°C with a doubling in CO_2 concentration	Increase in frequency of heavy rainfall events	(23)
All-India	Area-averaged annual mean surface temperature rise is projected to range between 3.5 and 5.5°C by the end of the century, More warming in winter Season.	Increase of about 7 to 10% in annual men precipitation. Decline of 5-25% in winter precipitation. Increase in monsoon precipitation is 10-15%. Monsoon season over northwest India-increase of 30% or more in rain fall by 2050. Westen semi-arid region of India could receive higher than normal rainfall in a warmer atmosphere. Decrease in winter precipitation between 10 and 20% over central India by 2050.	(24)

and regional model indicated that the changes in runoff were more dramatic for the months when the runoff was already very small (10). To study the effect of climatic variations on the design an operation of water resources projects, the response of hypothetical reservoirs of two drainage basins of India to climate variations was studied (9). The results of this study indicated that high probability of significant effects of climate change on reservoir storage. Hydrological modeli8ng have used earlier (11) to quantify the impact of climate change on the water resources of the country. The SWAT (Soil and Water Assessment Tool) was used to carry out the hydrologic modeling of various river basins in the country. The methodology for prediction of future monthly rainfall scenario in a metrological sub-division studied earlier (12, 13) using the fuzzy clustering technique on the general circulation model (GCM) outputs. A major advantage of the model is that while being computationally simple, it can produce a good prediction of rainfall with a high goodness of fit (R^2) value. The methodology was applied to predict the long-term monthly rain fall in orissa in India Figure 3.

Water resources management in India

In view of the existing status of water resources and increasing demands of water for meeting the requirements of the rapidly growing population of the country as well as the problems that are likely to arise in future, a holistic, well planned long-term strategy is needed for sustainable water resources management in India. The water resources management practices may be based on increasing the water supply and managing the water demand under the stressed water availability conditions. Data monitoring, processing, storage, retrieval and dissemination constitute the very important aspects of the water resources management. These data may be utilized not only for management but also the planning and design of the water resources structures. In addition to these, now a days decision support systems are being developed for providing the necessary inputs to the decision

Table 4. Selective reports on impact on water resources during next century over India. Source (21).

Region/location	Impact	Reference
Indian sub-continent	Increase in monsoonal and annual run-off in the central plants. No substantial change in winter run-off.	(25)
Orissa and West Bengal	One metre sea- level rise would inundate 1700 km^2 of prime agriculture land.	(26)
Indian coastline	One metre sea-level rise on the Indian coastline is likely to effect a total area of 5763 km^2 and put 7.1 million people at risk.	(27)
All-India	Increases in potential evaporation across India.	(28)
Central India	Basin located in comparatively drier region is more sensitive to climate changes.	(29)
Kosi Basim	Decrease in discharge on the Kosi River. Decrease in run-off by 2-8%	(30)
Southern and Central India	Soil moisture increases marginally by 15-20% during monsoon months.	(31)
River basins of India	General reduction in the quantity of the available run-off, increase in Mahanandi and Brahmini basins.	(32)
Rajasthan	Increase in evapotranspiration	(33)

makers for water resources management.

Data monitoring and information system

For planning design and operation of the water resources projects, temporal and spatial data of various hydro meteorological variables as well as basin characteristics are required. However, in India the network of monitoring the hydro meteorological variables is inadequate. Also the data collection, processing, storage and dissemination are not well organized. In this regard, a comprehensive, reliable and easily accessible Hydrological Information System (HIS) is a pre-requisite. To achieve these objectives, there is a need to strengthen the existing monitoring network of data and develop the HIS by improving the data processing, analysis and dissemination techniques through proper coordination amongst the various agencies. This onformation system will be useful for processing, storage and dissemination of the reliable and spatially intensive data on water quantity in computerized databases. Recent techniques, such as remote sensing and Geographic Information System (GIS) coupled with field-based monitoring stations may be utilized to monitor the data in real time and update the database. Decision Support System (DSS) could effectively improves the water resources planning and management.

Conclusion

This article reviewed various studies on Impact of climate change on water Resources in India. Present studies show consistency in temperature rise over India/Indian sub-continent with global temperature increasing trend. In the context of Indian water resources scenario an understanding of the impact of global climate change on water availability and demands, as well as intensity and frequency of hydrologic extremes of floods and droughts is vital. To determine the trend of temperature and rain fall on basin, regional and country more basic studies are needed. Current research in the country on the development models, methodologies and decision teels for the operational management of water resources should be enhanced to integrate the climatic related hydrologic forecasting products and tools. In the Indian context research program should be developed using remote sensing, GIS technologies and climate change models for monitoring climate, water resources and impact analysis of climate change on horticulture crops. These techniques would be useful to develop policies of sustainable management of water resources system.

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