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Impact Of Climate Change On Water Resources Of India

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Abstract

A significant anthropogenic hazard to the global environment is climate change. Climate change's direct and indirect effects will be detrimental to regional agriculture, food security, human systems, and water resources. With only 4% of the world's water resources and around 9% of the world's arable land, India, which has a population of more than 1.2 billion, has witnessed unprecedented economic growth in the last two decades. The need for water has grown significantly throughout time as a result of population growth, expanded agriculture, fast industrialisation, urbanisation, and economic growth. In addition, uncontrolled use of surface and groundwater resources, careless disposal of industrial and municipal waste, and the use of agricultural inputs have all contributed to the issue of water quality degradation and contamination, creating additional difficulties for water management and conservation. A warmer climate may cause the hydrological cycle to intensify, causing higher rates of evaporation and more liquid precipitation. The hydrological cycle is now being altered quantitatively and/or qualitatively across the majority of India's agroclimatic regions and river basins due to human activities including altered cropping patterns, changes in land use patterns, overuse of water storage, irrigation, and drainage. Given the foregoing, sustainable management of water resources and the surrounding environment has become increasingly important in recent years. For appropriate national and regional long-term development strategies and sustainable development, it is essential to assess the availability of water resources in the context of future national requirements, paying particular attention to the growing demands for water and anticipated impacts of climate change and variability. It is necessary to take action to safeguard water supplies and reduce the factors contributing to climate change and its negative effects..

Keywords- global environment, Impact Of Climate Change, food security, human systems, Water Resources.

Introduction

In India, where 1.2 billion people live, climate change poses a serious threat to their wellbeing as well as their access to clean water and food. India's water resources are distributed unevenly across several of its regions, from the northeast, which receives the most rainfall on earth, to the arid northwest, where rainfall is limited. In recent decades, India has endured a number of devastating climate extremes. For instance, the 2016 drought, which affected roughly 330 million people and affected about 10 states, cost the economy $100 billion (ASSOCHAM Report 2016). With only 9% of the world's arable land used for agriculture, India feeds 17.2% of the world's population, and more than 56% of its total agricultural area is rainfed (Singh et al. 2014b; Rathore et al. 2014). India has 16% of the world's population and 2.4% of the world's land area, but only 4% of the world's total freshwater supply. Its 328.726 Mha geographic region is traversed by numerous minor and major rivers. The consequences of climate change on water resources in India, a big nation with a diverse landscape, vary significantly among various regions and river basins and cannot be generalized. There is still a gap in the interdisciplinary aggregation of information regarding how climate change would affect India's water resources. Since climate change creates conditions that are outside of past bounds for current and future planning, reliance on historical climate conditions will no longer be tenable. With a focus on drought and flood, we give a thorough study based on available data from observed recent trends and climate model projections. This paper provides a comprehensive assessment of the research done to determine how climate change is affecting India's water supplies. In addition to serving the irrigation needs of roughly 50% of irrigated farmland, groundwater has been the principal source for providing residential water to more than 80% of rural and 50% of urban populations. Even though groundwater makes for roughly half of the region's water supply, less is known about how variations in rainfall affect the groundwater resources. The complicated connections between land use, aquifer characteristics, historical water table levels, and the actual timing and severity of individual rainfall events are largely to blame for this. Reductions in rainfall may not have an immediate impact on water tables in situations when the aquifer systems are almost full, but in other situations, a reduction in rainfall below a certain level could completely remove all infiltration outside of the vegetation root zone. Shaver et al. (2000) assert that the Earth's weather is altering as a result of the changing climate. As a result, the local climate is also altered, particularly in terms of rainfall and temperature (Shan et al., 2015).The impact of climate change on water resources is a major threat to India's 1.3 billion people's water and food security. India generates a water potential of 1122 BCM with 690 BCM of surface water and 432 BCM of groundwater from its average annual rainfall of 1105 mm (Table 1).

Table 1.
Water resources of India (Central Water Commission 2019-2020)

Average Annual Rainfall (1985-2015)	1105 mm (3880 BCM)
Annual Rainfall (2018)	1074 mm
Mean Annual Natural Runoff	1999.2 BCM
Total Utilisable Water	1122 BCM
Estimated Utilisable Surface Water Potential	690 BCM
Total Replenishable Ground Water Resources (2013)	432 BCM
Net Ground Water Availability (2013)	411 BCM
Ultimate Irrigation Potential	139.9 Mha
From Surface Water	76 Mha
From Ground Water	64 Mha
Storage Available Due to Completed Major & Medium Projects (Including Live Capacity less than 10 M. Cum)	253 BCM
Estimated Additional Likely Live Storage Available due to Projects Under Construction / Consideration	155 BCM

SURFACE WATER RESOURCES- The Himalayan river systems, which drain the country's main plains, are the most notable of India's extensive and intricate network of river systems. In addition, the subcontinent has many water bodies, making it one of the wettest regions of the planet after South America. The country's primary supply of water is expected to be an annual precipitation, which includes snowfall, of around 4000 km^3. According to the Central Water Commission's most recent estimates by basin, when both surface water and groundwater are taken into account as a single system, the country's resource potential, which manifests as natural runoff in the rivers, is around 1869 km^3.The system of the Ganga, Brahmaputra, and Meghna contributes most to the nation's total water resource potential. About 60% of the potential water resources of all the rivers are represented by it. According to the 2001 Census, there are 1820 m^3 of freshwater resources available per person. It has been predicted that only roughly 1122 km^3 of the total potential of 1869 km^3 can be put to productive use, with 690 km^3 attributable to surface water resources. This is because of numerous topographical limits and an uneven distribution of resources over space and time. In the Ganga-Brahmaputra-Meghna system, again, around 40% of surface water resources that can be used are currently found. The majority of river basins are currently using between 50% and 95% of their available surface resources, which is a very high level of utilisation. However, the percentage of use in rivers like the Narmada and Mahanadi is extremely low. These basins' respective equivalent values are 23% and 34%. The Southern States of Andhra Pradesh, Karnataka, and Tamil Nadu contain the majority of the area covered by tanks and ponds. Together with West Bengal, Rajasthan, and Uttar Pradesh, these states make up 62% of the nation's total area covered by tanks and ponds. Major states like Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, and Uttar Pradesh make up a bigger share of the land covered by reservoirs than other states. Our rivers contain freshwater that has promising potential. However, India is already experiencing water stress as a result of improper river management. The restoration of and recent focus on the traditional practices of collecting rainwater and boosting groundwater recharge via abandoned bore wells offers enormous potential and will undoubtedly help alleviate water stress (Manivannan et al., 2017). However, relying solely on these options may not completely address the issue of water in the present or the future because they too have limitations, such as the need for access to large land areas and a reliance on precipitation that is subject to significant intraseasonal and interannual fluctuations. Without the construction of significant hydrological projects, we might not be able to guarantee food security and a consistent water supply for the nation, notwithstanding the environmental and social disruptions brought on by major dams. Through the use of cost-benefit analyses that take into account environmental and social costs, these projects' effects can be controlled, damages can be reduced, and their viability can be considered. Figure 1 depicts the population growth from 1951 to 2050 along with the observed and anticipated drop in the average annual freshwater availability per person. This demonstrates the "two-sided" impact that population growth will have on water supplies. The increased demand for water will cause water to be withdrawn more quickly, which will shorten the time it takes for water tables to recharge. As a result, availability of water is bound to reach critical levels sooner or later.

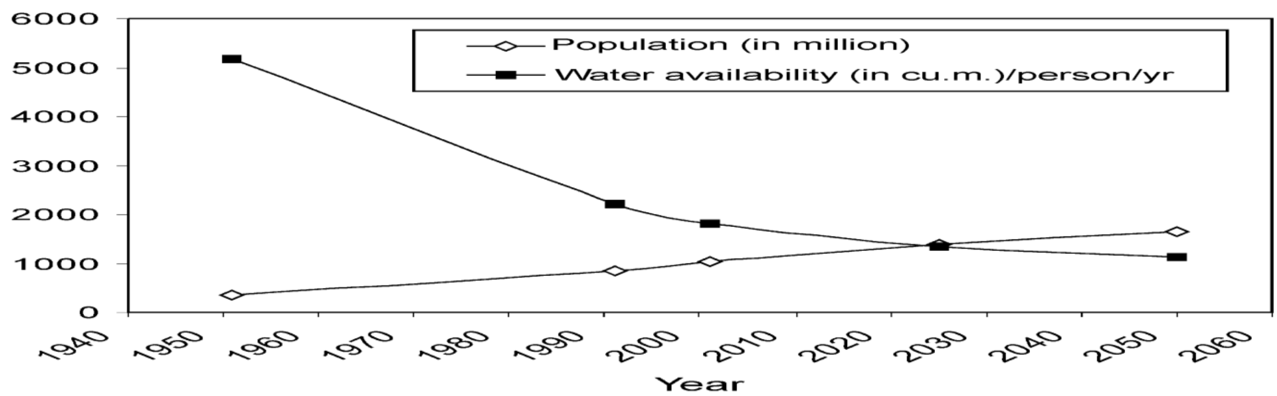

Figure 1. Observed and projected decline in per capita average annual fresh water availability and growth of population from 1951 to2050.

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GROUNDWATER RESOURCES - India is a huge country with a diverse geological, climatological, and geographical environment, which results in varying groundwater conditions throughout the nation. The common rock formations that influence the presence and movement of groundwater range in age from Archaean to Recent and have a wide range of compositions and structures. The many landforms, which range from the rocky mountainous terrains of the Himalayas, Eastern and Western Ghats, to the flat alluvial plains of the river basins and coastal tracts, as well as the aeolian deserts of Rajasthan, are also not inconsequential. The pattern of rainfall also exhibits comparable regional variances. Runoff and groundwater recharge are largely controlled by topography and rainfall.

Due to the implementation of technically sound plans for resource development, generous funding from institutional finance agencies, improved availability of electric power and diesel, high-quality seeds, fertilisers, government subsidies, etc., the growth of groundwater abstraction structures has been phenomenal over the past forty years. Dugwells increased from 3.86 million to 10.50 million in number between 1951 and 1997, shallow tubewells from 3000 to 6.74 million, and public bore/tubewells from nil to 90,000. Diesel pumps have increased from 66,000 to roughly 4.59 million, while the number of electric pump sets has increased from zero to 9.34 million (Chadha and Sharma, 2000). Groundwater irrigation has steadily increased, from 6.5 Mha in 1951 to 41.99 Mha in 1997.1.71 million dug wells, 1.67 million shallow tubewells, and 114,000 deep tubewells were installed during the VIII Plan. Growing water needs in the home, industrial, and agricultural sectors have led to issues with groundwater overuse, steadily dropping water levels, seawater intrusion in coastal areas, and groundwater pollution across the nation. The sustainability of the nation's groundwater resources is under jeopardy due to the country's declining groundwater levels, which have caused water levels to rise above what can be economically pumped. To monitor the water level and its quality, the Central Ground Water Board has set up over 15000 network monitoring stations across the nation. Major regions of the nation normally do not experience any notable rises or falls in the water level. However, there have been 289 districts in the states of Andhra Pradesh, Assam, Bihar, Chhattisgarh, NCT Delhi, Jharkhand, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamilnadu, Tripura, Uttar Pradesh, and West Bengal that have seen a significant decline in groundwater levels.

Table 2.
Impact on water resources during the next century over India (Mall et al., 2006)

Region/location	Impact
Indian subcontinent	Increased evaporation and soil moisture during the monsoon and on a yearly basis, as well as a rise in monsoonal and annual run-off in the central plains
Orissa and West Bengal	One metre sea-level rise would inundate 1700 km^2 of prime agricultural land
Indian coastline	One metre sea-level rise on the Indian coastline is likely to affect a total area of 5763 km^{2}and put 7.1 million people at risk
All-India	Increases in potential evaporation across India
Central India	Basin located in a comparatively drier region is more sensitive to climatic changes

Kosi Basin	Decrease in discharge on the Kosi River 84 Decrease in run-off by 2–8%
Southern and Central India	Soil moisture increases marginally by 15–20% during monsoon months
Chenab River	Increase in discharge in the Chenab River
River basins of India	General reduction in the quantity of the available run-off, increase in Mahanadi and Brahmini basins
Damodar Basin	Decreased river flow

Table 3.
Utilizable water, requirement and return flow over the years (NCIWRD, 1999)

Particulars	1997-98	2010		2025		2050	
		Low Demand	High Demand	Low Demand	High Demand	Low Demand	High Demand
Utilizable water km^3							
Surface	690	690	690	690	690	690	690
Ground	396	396	396	396	396	396	396
Canal Irrigation	90	90	90	90	90	90	90
Total	996	996	996	996	996	996	996
Total water requirement							
Surface	399	447	458	497	545	641	752
Ground	230	247	252	287	298	332	752
Total return flow	629	694	710	784	843	973	1180
Surface	43	52	52	70	74	91	104
Ground	143	144	148	127	141	122	155
Total	186	196	200	197	215	213	259
Residual utilizable water							
Surface	334	295	284	263	219	140	42
Ground	219	219	202	146	149	96	33
Total	553	553	486	409	368	236	75

RAINFALL TRENDS IN INDIA- In India, the southwestern monsoon between June and September is responsible for nearly 80% of the country's yearly precipitation (Lacombe and McCartney 2014). No discernible pattern is found for yearly rainfall on a national scale using 306 stations across India and 135 years of data (1871-2005). The annual rainfall did, however, show a tiny declining tendency across all of India, whereas northwest and peninsular India showed a small growing trend (Kumar et al. 2010; Mondal et al. 2015). No discernible trend in rainfall was seen between 1871 and 2008 in northeastern India, the region receiving the most rain on Earth (Jain et al. 2013). In India, there was an increase in heavy rainfall events and a decrease in low and medium rainfall events (Goswami et al. 2006).During the period 1951–2010, a substantial declining trend of the mean July and August rainfall was seen in central India (10% significance level) (Singh et al. 2014b). There were fewer rainy days and more intense events in a number of significant river basins (Jain et al. 2017). Using 18 Coupled Model Intercomparison Project Phase 5 (CMIP5) models across India, average annual precipitation is projected to rise by 7–18.7% for various representative concentration trajectories (RCPs) by 2099 compared to the 1961–1990 baseline (Chaturvedi et al. 2012).Using observed data for the years 1971–2005, five general circulation models (GCMs) of the CMIP5 are anticipated to show an increase in precipitation of up to 30% in the midterm (2040–2069) and 50% in the longterm (2070–2099) in many river basins across India (Mishra and Lilhare 2016). Using the PRECISE (Providing Regional Climates for Impacts Studies) simulation with the A2 scenario and the base period of 1961–1990, a premonsoon rainfall increase of roughly 100 mm is predicted for the Brahmaputra basin (Ghosh and Dutta 2012).

According to a recent survey, the amount of precipitation has the greatest impact on the district of Varanasi's water supplies. The data shows that the Varanasi region saw a constant decline in precipitation during the same time periods of analysis, as well as a modest fall in mean air temperature during the 1950s and 1980s. Because of this, the values of the seasonal and annual ETc as well as the AETc somewhat reduced between these two periods. The primary effect was the decline in precipitation, which also directly affected the study area's water supplies (Nistor et al, 2019).The majority of India's irrigated areas are predicted to need more water around 2025, and global net irrigation needs are predicted to rise by 3.5–5% by 2025 and by 6-8% by 2075 compared to the current state without climate change. By building micro-storage facilities in watersheds, it may be possible to lessen the impact of climate change on water resources. These would replenish the groundwater aquifers in addition to serving as additional irrigation (Pathak et al., 2014).

RIVER RUNOFF- Despite having a total fresh water resource of 1.91 km3 per year, India ranks 132 in the world in terms of water availability per person and has 17.2% of the global population (UNFAO 2013). Water resources are unevenly dispersed across space. For instance, the amount of water available per person in the Brahmaputra River basin in the northeast of the nation is 17,000 m^3, whereas it is 240 m^3 in the Sabarmati River basin in western India (Amarasinghe et al., 2005). In 41 years (1970-2010) of daily streamflow records for the Sutlej River in northern India, a diminishing trend has been noted at three gauging points (Kasol, Sunni, and Rampur).The basin has importance in the high potential for hydroelectricity power generation and agricultural practices (Singh et al. 2014a). With the exception of one gauging station (T. Narasipur), no notable trends in the monthly streamflow data during a 30-year period (1981-2010) for the four gauging stations have been found in the Upper Cauvery basin of southern India (catchment area of 36,682 km2) (Raju and Nandagiri 2017). In peninsular India, streamflow at the Mahanadi River basin's exit (Tikerpara) decreased at a rate of 3,388 million cubic metres per decade from 1972 to 2007 (catchment area: 141,589 km^2) (Panda et al. 2013). There has been an upsurge in specific flood incidents at Bahadurabad along the Brahmaputra River between 1956 and 2007, according to records (Climate Change Cell 2009).The Himalayan river basins, such as Brahmaputra and Indus, are projected to have reduced upstream flow based on GCMs for the SRES A1B scenario over the period 2046–2065(Immerzeel et al. 2010). Based on 22 GCMs and the A1B, B1, and A2 scenarios, the Brahmaputra riverflow near Chilmari is predicted to rise by 5-20% in 2100 (Mahanta et al. 2014). At the lower Meghna Basin's outlet, monsoon flow is anticipated to rise by 4.5 to 39.1%, including seasonal flow changes (Kamal et al. 2013). According to Had CM3 GCM and the A2 and B2 scenarios, an increase in the average annual streamflow of the Tungabhadra River of 5.4-17.1% is anticipated by 2050. (Meenu et al. 2013). Asokan and Dutta (2008) predicted that the peak runoff in

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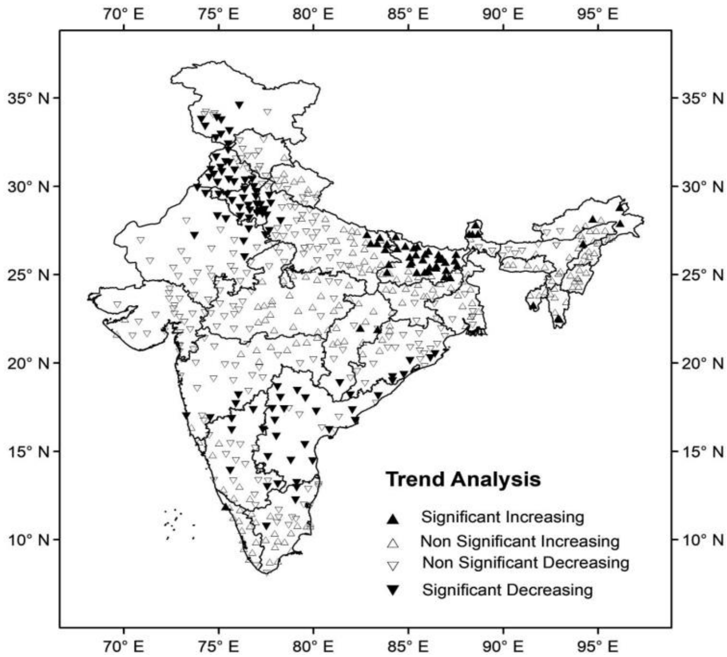
Mahanadi would increase by 38% in September for the period 2075-2100, indicating an increase in floods; and that the average runoff would fall by a maximum of 32.5% in April for the period 2050-2075, indicating drought conditions.

DROUGHT- Every year, a substantial number of inhabitants in India are impacted by drought, a spatially broad phenomenon. Regarding food security and socioeconomic fragility, it is concerning that 33% of the region is experiencing drought conditions (Mishra and Desai, 2005), which are mostly caused by irregular monsoon rainfall (Shah and Mishra 2015). An area of 2.28 106 km^2 is made up of dry areas (arid, semi-arid, and dry subhumid) that stretch from western to southern India (Ministry of Environment and Forests 2010). India experienced extremely severe droughts in the 1960s (1965), 1970s (1972 and 1979), late 1980s (1987), and late 2010s (2009), which devastated more than 40% of the country's land (Kaur 2009).In central India, extreme dry spells increased in frequency from 1981 to 2010, but they were less severe than they were from 1950 to 1980 (Singh et al. 2014b). With 31 drought episodes between 1875 and 2004 (130 years), the Indian Meteorological Department names the dry western meteorological subdivision, which includes West Rajasthan, Saurashtra, and Kutch, as the most drought-affected region in India (Shewale and Kumar 2005). Gujarat saw 27 occurrences of drought, while the Jammu and Kashmir meteorological subdivision suffered 28. The Northeast has had the fewest recorded droughts (Shewale and Kumar 2005).



In compared to 1901-1935 and 1936-1971, an analysis of the drought trends revealed an increase in drought severity and frequency from 1972 to 2004. Additionally, the agriculturally significant coastal southern India, central Maharashtra, and Indo-Gangetic plains have all seen an overall shift in the drought (Mallya et al. 2015). Compared to yearly drought statistics over the past three decades, meteorological, vegetation, and short-term droughts are becoming more severe (Zhang et al. 2017). Figure 2 displays the nonparametric Mann-Kendall test trend analysis for ADS. The northeastern, central eastern, and southern regions of the nation all showed rising trends for ADS. However, the northern regions, particularly Bihar State, have a markedly rising trend for ADS.Decreasing trends were found for the western, northwestern, and southern regions of the country.

Figure 2. Trend analysis of annual drought severity (ADS) across 566 stations in India over 1901–2002.

IMPACT ON WATER DEMAND- According to the 1991 Census, only agriculture uses more than 83% of the available water, and the average amount of waterworks per person is 1967 m^3. Only about 1122 km^3 of its total potential is frequently used, with 690 km^3 coming from surface water resources, due to topographic constraints and uneven resource distribution over place and time. Furthermore, almost 40% of the world's currently usable surface water resources are found in the Ganga, Brahmaputra, and Meghna systems. The majority of river basins currently consume between 50% and 95% of the utilisable surface resources. However, rivers like the Narmada and Mahanadi only use 23% and 34% of their total capacity, respectively. In the upcoming years, spring water use is anticipated to rise sharply, enabling the expansion of irrigated agriculture and the accomplishment of national food production targets. Although spring water is a regenerative resource that refills itself annually, it is not always readily available. As a result, the Central Spring Water Board and the state governments determined that the gross spring water recharge was 431.42 km^3 and the net (70% of the gross) recharge was 301.99 km^3. The amount of land irrigated increased with time, as did the amount of water needed for cultivation. In India, irrigated land increased from 22.60 million ha in 1947 to 80.76 million hectares in 1997 over a 50-year period. The surface and groundwater resources has considerably contributed for India's achievement of food self-sufficiency over the last three decades (Dutta et al., 2015). Still, it is projected to become much more criticalin the future, given national food security and global climate change.

IMPLICATION OF CLIMATE CHANGE AND POLICY ACTIONS- India is a developing nation with the biggest percentage of the world's poor people (30%). It also has an agrarian economy, a longer 7,517 km coastline, the Himalayan area, and islands. Climate change poses a serious threat to the nation's water resources in terms of variations in rainfall quantity and intensity, groundwater recharge, floods, and drought disasters, as well as contamination of surface water and groundwater resources. The Indian Government's National Water Policy was originally announced in 1987. The ecological and environmental implications of water allocation in the context of rapid climate change were highlighted in the National Water Policy of 2002. For the purposes of planning and managing water resources, the National Water Policy (National Water Policy of India, 2012) emphasised that water must be viewed as a common-pool resource. Because of many factors at local, regional, national, and international echelons and their enforcement challenges, water law continues to be uneven and relatively inadequate in the 21st century (Kumar and Bharat 2014), despite various policies made by the government at various levels. In India, there has been a decrease in the plant proportion and a rise in the urban and bare soil fractions. Weather forecasting and water resource management can be made better by incorporating changes to land use and cover (Unnikrishnan et al. 2016).Because of this, the effects of climate change in a particular basin depend on how the land is used there. In order to make informed decisions about climate change projects, high resolution land-use analysis is required. The comprehensive land-use maps produced by this study are a promising first step toward making it possible to accurately estimate the impact of climate change.

This can be viewed as a unique quality and benefit in terms of the techniques used in this study, particularly with regard to their use in the Upper Kharun basin. The ability to develop targeted recommendations on land use management that are appropriate to mitigate the impact of climate change on the water balance is another benefit of taking into account the type of land use, crop rotation, and irrigation amount in detail while estimating the impact of climate change. This is especially useful when aiming for an integrated approach to water management (IWRM).

FUTURE PROSPECTS- From a practical standpoint, it can be said that there is a significant gap between the amount of thorough research that has been done on the effects of climate change on water resources for the study area and the urgent need for the relevant information to develop timely adaptive water management strategies (Kumar et al., 2017). By making improvements at the field, farm, command area, and basin levels, water productivity can be increased on all scales. Water demand management will be aided by multiple uses of water, assuring the hydrological sustainability of intensive cropping systems, lowering unfavourable evaporation losses, developing drought- and flood-tolerant and water-efficient cultivars, and community involvement in resource management. There is an urgent need to improve data access, modernise data gathering networks and storage, and support multidisciplinary research institutes around the nation in order to address future issues with water resources. Making scientific decisions about water and climate change policy will be aided by this.

CONCLUSIONS- In certain parts of the country, the effects of climate change are anticipated to become more pronounced. Up to 2040–2050, there will be a steady decline in glacier area and snowfall, and then it will turn around. As evapotranspiration rises, water supply may decline, and water demand will be on the rise. Extreme rainfall events must be taken into account when calculating peak discharge for the construction of structures since the peak discharge rate will be high, resulting in frequent floods. As a result, necessary designs must be made to protect the water harvesting structures. Planning and management of water resources will be impacted by changes in precipitation in a number of ways, including the design of hydrological structures, managing floods and droughts, and urban planning and development. The agriculture economy of India is particularly vulnerable to the anticipated climatic changes since it depends so strongly on the monsoon and the availability of water for output. Therefore, it is crucial to enhance the assessment of the effects of climate change and to adapt methodologies employing hypothetical futures. Existing water resource systems, including monitoring, processing, communication, dissemination, and storage networks, have significant data collecting gaps and are unable to handle the anticipated problems posed by a fast changing environment.

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