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Impact of Climate Change on Hydrological components of Indian River Basins - A Comprehensive Review

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ABSTRACT: The world is facing a water crisis due to unexpected transformations in the hydrologic cycle, which is the primary reason for any natural disaster. This happens due to the growing population and fast urbanization, which hampers the organisation and administration of water resources sustainably.Climate change adversely affects an area's ecosystem, wildlife, agriculture, etc., thereby altering the socio-economiclife of many. Most of India's people dependon agriculture either directly or indirectly. The productivity from agriculture is immensely decreasing due to the impact of climate variations nationwide.In the twenty-first century, climate change has become a major concern which is mostly prevalent by the human interventions. Climate change may be a global phenomenon, but its impacts are local. Rapid industrialization and urbanisation in India are responsible for massive increase in water demand, leading to a water crisis that is becoming prevalent as the surface and groundwater resources areshrinking due to climate change and other hydrological parameters. A larger number of studies have been reported on climate change's impact on water resources, but the understanding of the effects of climate change on India's river basins is still incomplete from an interdisciplinary perspective. In order to lessen the impact of climate change on river basins, it is thus appropriate to assess recent research and suggest potential topics for future study.
This paper comprehensively reviews the significance of climate change on hydrological balance of river basins of India.

Keywords: Climate change, climate projection, global warming, water resources.

INTRODUCTION

The climate is defined as the normal weather condition of a zone. Statistically, it may be defined as the mean and variability of weather conditionsover a long time. The duration may vary from few months to millions of years (IPCC, 2014). Climate change refers to changes in the weather pattern, like shifting temperature which occurs due to human intervention. It was seen that any changes in climatic conditionsaffects the surface runoff, soil erosion, and sediment yield of a river basin (Nearing *et al*., 2005; Phan *et al*., 2011; Lilhare *et al*., 2014). A standard method for assessing climate change affecting watershed hydrology is by constructing a hydrological model that considers various changes in the climatic inputs (Srinivasan*et al.*, 1998; Gosain *et al.*, 2006; Johnston and Smakhtin 2014). Rainfall and temperature being the fundamental physical parameter of climate (Singh *et al.*, 2013) governsthe meteorological conditions. The annual temperature of the earth is likely to extend from 0.3 to 0.6 by near future (IPCC, 2014) which canalter the recurrence and severity of precipitation as well as the atmospheric CO_2 concentration. Mainly any change in temperature and rainfall affects the agricultural yield and productivity of the crop (Modarres and da Silva 2007; Kumar and Gautam 2014) immensely. The crop yield sinks by 3-5% for every one °F rise in temperature,as reported by (Shah and Srivastava 2017). This temperature rise, when prolonged, may induce drought, which reportedly causes a loss in crop yield, as found by Auffhammer *et al*. (2012). In addition to reducing soil moisture, the temperature increase the need for irrigation water (Venkateswar and Singh 2015), ultimately decreasing the groundwater level and leading to more groundwater extraction (Zaveri *et al*., 2016). The release of greenhouse gases (GHGs) is another reason for the temperature rise(GHGs) (Montzka *et al*., 2011). Apart from the temperature, the precipitation also plays a vital role in climate change.

Moreover,with the change in rainfall, the streamflow changes (Milliman *et al.*, 2008), which is closely relevant to water accessibility. The growing population and ineffective land use have affected water resources in recent years. As the necessity of water increases, precipitation and temperature influence the water resources (Jia *et al.*, 2017). So to maintain a proper balance between the supply and demand of water resources the management of resources isessential.

Hence, for the proper management of water resources,many hydrological and eco-hydrological models (Arnold *et al*., 1998; Williams *et al*., 2008; Arnold *et al*., 2012a; Bieger *et al*., 2016) were employed. As temperature, precipitation and streamflow are essential parameters, several researchers have worked on different Indian River basins tosurvey the influence of climate change on these parameters. Fig. 1 shows that the number of studies has increased over the last few years. Mishra and Lilhare (2016) surveyedthe Ganges and Godavari river basins, compared surface runoff and evapotranspiration, and found that the surface runoff is more susceptible to change due torainfall and temperature than evapotranspiration. Similarly, for the Mahanadi River basin Rao (1995) found a slight decrease in precipitation and Panda *et al*. (2013) observed an upsurge in streamflow.

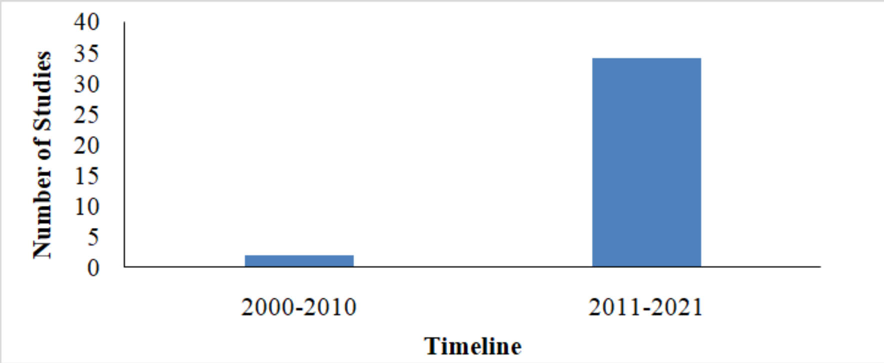

Fig. 1. Number of climate change studies done in India during the twenty-first century.

This paper exhibits the influence of climate change on the watershed hydrologic process.With the use of climate and hydrological models in several watersheds, this study primarily focused on the effects of global climate change on the hydrological responses of a watershed. In addition, trend analysis of temperature, rainfall, and other climate variables was used based on various regional scales for future climatic metrics (Ganguly *et al*., 2015). The reviews were collected for different watersheds under various river basins of India.

OVERVIEW OF CLIMATE CHANGE

Climate change has been afundamental challenge for the entire globe inthe 21st century. Being said this, our country is also affected by it. India's temperature has been increasing by one as reported by (IPCC, 2001a and 2001b). Many scientists have designed several strategies to adapt and lessen the impact of climate change by foreseeing the future climatic condition. The parameters which get affected due to climate change are hydrology and water resources (Arnell, 2003; Barnett, 2008).

Various researchers worked on different approaches to know the impact of climatic parameters under changing scenarios. Several models are being used for predicting future scenarios, GCM being the most commonly used model irrespective of its complexity (Schaller *et al*., 2011) and expensiveness (Alotaibi *et al*., 2018). Recent studies (Hao *et al*., 2018; Grusson *et al*., 2018; Makhtoumi *et al*., 2020) statedthat hydrological models driven by GCMs were used to understand the climate change impact on hydrological processes. (Ficklin *et al*., 2010; VIC (Bae *et al*., 2015). These hydrological models incorporate projections generated by GCMs to know the long-term hydro-climate changes. The GCMs were also used,coupled with other models, to know various hydrologic parameters. A study was conducted by connecting GCMs withatmosphere-ocean general circulation models (AOGCMs) (Chen *et al*., 2012),where they reported no decline in wind speed. Likewise, the hybrid-delta method uses several GCMs projections to know the scenario over the Gomti river basin (Abeysingha *et al*., 2018). They reported a rise in annual rainfall and streamflow.It was also anticipated that high flows might become more frequent and significant. Similarly, Vandana *et al*. (2019) found an increase in temperatureand precipitation over the Brahmani River basin each year using the hybrid-delta method. But while using GCMs the best ranking GCM is to be used. GCMs have a lot of room for error regarding precipitation and temperature. To avoid it, Schaller *et al*. (2011) have used different methods for evaluating the CMIP3 climate models to identify the most accurate model required. Another study by Cai *et al*. (2009) found that no GCM was excellent for predicting temperature orrainfall for the entire world. Some GCMsmay work better for a particular region than other regions. The skill score maps can be helpful to know about GCMs data better based on its information by overlaying these score maps with maps of global climate zones, land cover and elevation (Cai *et al*., 2009).

FUTURE TREND OF RAINFALL AND TEMPERATURE

Sen's non-parametric estimator is typically used to estimate the trend's magnitude for trend analysis, and the Mann-Kendall test is then used to assess it further. The analysis was done for different Indian River basins to predict the future impact of climate change. Trend analysis study for the major basins were taken into consideration i.e., Ganges, Brahmaputra and Meghna (GBM) river basins (Mirza *et al*., 1998), they have reported that among all the river basins Ganga basin's precipitationwas steady, the Brahmaputra basinwhich hastwo subdivisions, showed trend in different directions. And lastly,the Meghna basin has three sub-divisions,of which two subdivisions showed an increasing trend, and the other one showed adecreasing trend. The trend analysis of temperature and precipitation was also studied for north east India by Laskar *et al*.(2014); Jain *et al*. (2012). They have found that the minimum, maximum and mean temperature increase. Joshi and Pandey, 2011 also observed the same as Laskar *et al.* (2014); Jain *et al*. (2012) found nodiscernible pattern in climate change during 1901-2001. Similar results were observed by Jain and Kumar (2012) when they studied for Indian River basin, where no rainfall trend was seen over the years but a remarkable increase in temperature was found over the past century (Dash and Hunt 2007; Subash and Sikha 2014). Panda and Sahu (2019) studied for Odisha districts ofKalahandi, Bolangir and Koraput. They found an increasing trend in rainfall,whereas the temperature was more or less the same in all seasons. Therefore, they have concluded that the temperature variation did not significantly affect agricultural productivity during the experimental conditions.

Manystudies were also conducted on streamflow and precipitation for the Gomti river basin (Abeysingha *et al*., 2014; Das *et al.,* 2021; Pal and Mishra 2017). Das *et al*. (2021) found rise in temperature and fall in streamflow and precipitation, unlike Abeysingha *et al.* (2014), who noticed an increase in annual rainfall in upper areas and a decrease in lower areas for the basin. Pal and Mishra (2017) reported increased precipitation and temperature with a reduction in runoff over the catchment area. Study on the Indus river basin was also conducted by Rajbhandari *et al*. (2014); Khan *et al*. (2020). They observed an increase in temperature in the future. Similar findings were observed by Ougahi *et al*. (2022) along with the shifting of precipitation pattern and melting of snow and glacious, whichshifts the river flows. Apart from the increase in temperature, the intensity and frequency of the discharge also increased. For the upper Indus basin (Lutz *et al*., 2016) it was found prone to flood (Rajbhandari *et al.,* 2014). The upward trend in temperature was also seen in the Narmada river basin of about 0.2 per decade (Tiwari *et al*., 2021), while the Cauvery river basin experienced a decline in rainfall and streamflow (Sreelash *et al*., 2020).

CLIMATE CHANGE ON STREAMFLOW AND WATER BALANCE COMPONENTS

Several researchers have used different representative concentration pathways to quantify other climatic models. These models show the change in streamflow, precipitation, temperature, runoff, etc.,shortly. Sharannya *et al*. (2018) found arise in temperature and a fall in streamflow over India's Western Ghats. Similar outcomes were suggested by Rao *et al*. (2020); Jana *et al*. (2012). They studied for Subarnarekha River basin under RCP 4.5 and RCP 8.5 and found a reduction in rainfall with a decline in streamflow.However, for river Mahanadi, the streamflow tends to increase, as suggested by Dadhwal *et al*. (2010). Bisht *et al*. (2020), highlighted that low flow frequency would decrease predominantly under the projected climate for the Mahanadi river basin. Various other river basins such asBrahmaputra (Gain *et al*., 2011), Brahmani river basin (Sahoo and Kumar 2015), upper Indus basin (Ougahi *et al*., 2022), Krishna river basin (Chanapathi and Thatikonda 2020; Kulkarni *et al*., 2014), Satluj river basin (Talib *et al*., 2017) and Godavari river basin (Pandey *et al*., 2016; Hengade *et al*., 2018) showed the similar result as that of Mahanadi river basin.In contradiction, Gomti river basin shows a decrease in streamflow with increased temperature (Das *et al*., 2021; Abeysingha *et al*., 2021). As the climate cause an impact on temperature, precipitation and streamflow, eventually,it affects agricultural practices, as suggested by several reviewers. Padhiary *et al*. (2019) reported a shifting of conventional farming practices of the Baitarini River basin with the increase in temperature and rainfall stipulated by an ensemble of 2 different CMIP5 models. The same model was used by Janapriya *et al.* (2016) over the Wangchu river basin in Bhutan and Raidak basin in India and reported a rise in streamflow and groundwater under RCP 4.5 and declines in RCP 8.5. Zam *et al*. (2021) also recorded a rise in temperature by 1.5 °C under RCP 4.5 and by 3.6 °C under RCP 8.5 over the transboundary river of Bhutan and India.

These models also predict the runoff affected by the changing climate. The surface runoff of the Krishna River basin (Kulkarni *et al*., 2014), Mahanadi River basin (Naha *et al.,* 2020) and Godavari River basin (Hengade *et al*., 2018) increases, whereas Thomas *et al*. (2017); Uniyal *et al*. (2015) found conflicting results for Bundelkhand region and Baitarini River basin respectively. Table 1 shows the location of different river basinsalong with their streamflow pattern. Apart from the above hydrological parameters, greenhouse gas emissions from human activity also impact climate (Montzka *et al*., 2011).

Table 1: Streamflow trend of Indian River basin.

River basin	Watershed/Catchment	Location	Increase in streamflow	Decrease in streamflow
Baitarani	Anandapur	Odisha	✓	
Raidak	Raidak	West Bengal		✓
Gomti	Gomti	Uttar Pradesh		✓
Brahmaputra	Lower Catchment	Assam		✓
Mahanadi		Odisha,Chhattisgarh		
Satluj		Himachal Pradesh, Punjab	✓	
Subarnarekha		Odisha, Jharkhand, West Bengal	✓	
Indus		Himachal Pradesh, Punjab, Haryana, Rajasthan, J&K.	✓	
Cauvery				✓

Pandey *et al*. (2016) reported a shift in hydrological properties and water yield due to the emission of GHG. Also, the severity of flood and drought was found to be declining under GHG scenarios (Gosain *et al*., 2006). Table 2 shows a tabular format about the models used and the research findings.

Table 2: Climate change study on Indian River Basins.

River Basin	Researchers	Climate model and IPCC-RCP scenario used	Findings
Mahanadi River Basin	Dadhwal *et al.* (2010)	Variable Infiltration Capacity (VIC) hydrological model.	Annual streamflow was expected to increase
	Naha *et al.* (2020)	CMIP6 GCM climate projections is incorporated into VIC.	Reduction of ET, and increase in baseflow and runoff in the future
	Bisht *et al.* (2020)	Nine GCMs, incorporated in MIKE 11 NAM-HD.	1. The streamflow increases 2. The daily high flows increases in their magnitude and frequency, and a decrease in low flows was found under projected climate.
Brahmani River Basin	Sahoo and Kumar (2015)	Precipitation runoff modelling system (PRMS)	Changes in precipitation have a higher impact on the flow of catchments than changes in temperature.
	Kumari *et al.* (2018)	Precipitation Runoff Modelling System (PRMS)	The high and low flows show increasing and decreasing trend, respectively. The streamflow decreases in winter and annual rainfall increases.
Brahmaputra	Gain *et al*. (2011)	Twelve different GCMs were used for both scenarios (A1B and A2),	1. Increase in peak flow 2. Less frequent extreme low flow conditions were seen with a sharp increase in peak flow
Subarnarekha river basin	Jana *et al.* (2015)	Regional climate model PRECIS, Hydrological model, HEC-HMS calibrated for the basin	Decrease in rainfall and streamflow in future
	Rao *et al*. (2020)	GCM and hypothetical climate change scenarios were analysed and compared under RCP 8.5 and RCP 4.5.	Availability of water substantially reduces due to significant warming, reducing the precipitation under the projected future.
Ganga basin	Chawla and Mujumda (2015)	Six GCMs were available from CORDEX project to obtain future projections of climate	Rainfall shows contradictory response in monsoon months where it decreases and for winter months it increases.
	Saha and Ghosh (2020)	VIC is used for the performance of Hydrological projections under RCP-SSP scenarios.	Rainfall decreases in monsoon season and increases in winter.
Baitarani River basin	Uniyal *et al*. (2015)	ArcSWAT model	With the decrease in surface runoff and baseflow and increase in evapotranspiration it was evident that there would alter the future scenarios by the end of 21st century.
	Padhiary *et al.* (2019)	Two different CMIP5 models under two RCPs,	1. The average annual streamflow and ET increases. 2. Reduction in groundwater recharge over the basin 3. Increase in the tendency of rainfall and temperature
Godavari river basin	Pandey *et al*. (2016)	HadRM3 is used as input to the model using SWAT.	All the parameters i.e. average annual temperature, average annual rainfall, evapotranspiration and water yield shows an increasing trend.
	Hengade *et al*. (2018)	CMIP5 GCM climate projections incorporated into VIC macroscale hydrological model	There is an increase in hydrological parameters
Krishna river basin	Kulkarni *et al*. (2014)	PRECIS (Providing Regional Climates for Impacts Studies) is used.	The hydrological parameters were seen to be increased.

	Chanapathi and Thatikonda (2020)	Three climate models, with both RCP 4.5 and 8.5 scenarios were used.	1. As pasture and urbanization are likely to increase, there is increase in irrigation and domestic water requirement in the future. 2. Evapotranspiration will increase in future.
Gomti River basin	Das *et al*. (2021)	GCMs projection under RCP 4.5 and RCP 8.5 used in SWAT model	Due to scanty rainfall and rise in temperature the stream flow decreases.
	Abeysingha *et al.* (2014)	Non-parametric test	Decrease trend in streamflow
Cauvery River Basin	Sreelash *et al*. (2020)	Mann-kendall and sen's slope estimator test	Decrease trend in rainfall and streamflow along with the declining of ground water
Indus River Basin	Ougahi *et al*. (2021)	GCMs under RCP 4.5 and RCP 8.5, applied in SWAT model	Increase in temperature with varying precipitation magnitudes.
	Lutz *et al.* (2016)	CMIP5 General Circulation Model outputs for RCP4.5 and RCP8.5	Uncertainty in water availability. Strong discharges occurs more frequently and with greater intensity.
	Khan *et al*. (2020)	GCMs available from CORDEX project applied in SWAT model	Increase in mean annual flow. Increase in flood hazard in the future
	Rajbhandari *et al.* (2014)	PRECIS (Providing Regional Climates for Impacts Studies) is used.	Precipitation increases in the upper basin while decreases in the lower basin. Lower rainfall intensity with higher rainy days

CLIMATE RESILIENT PRACTICES

According to IPCC AR5, global climate changes increase air temperature. It also adversely affects precipitation occurrence and distribution,thereby affectingthewater balance components. Climate change also adversely affects global food security and water availability. The United Nations Framework Convention on Climate Change (UNFCCC) proposed two options to combat climate change. First, to cut down GHGs emissions for mitigation and, secondly, to acclimatizetothe consequences of climate change. The earth's surface temperature and precipitation rateis erratic due to anthropogenic activities and increase in GHGemissions. Hence, suitable measures must be taken to restrainthe emission of GHGs concentration in the atmosphere. Furthermore, appropriate adaptation and coping mechanisms may help to moderate theharmful effects of changing climate.

CONCLUSIONS

Crop productivity and water resources are being impacted by climate change at an alarming rate.Most of the river basins show an increasing trend in rainfall, temperature and runoff. Increased precipitation and surface runoff has been increasing the intensity of flood. Groundwater is found to behave differently as there is an uprisein some cases under RCP 4.5 scenarios and a decreasing trend in a few instancesunderRCP 8.5. Some basins showoveruse of groundwater.The uneconomical use of groundwater is likely to worsen due to declining surface water resources in many regions.Irrigation for agricultural use isfound to bemore sensitive to climate change.Hence, water-saving irrigation practices would be one of the available techniques to address climate change-related water shortage and food security challenges. It is also recommended to use specific measures like changes in cropping patterns and breeding, and innovative technologies which require less water consumption in the agricultural sector. Decision-making plays a vital role in understanding sustainable risk management, which must be integrated into climate change improvement.

Given various climate models and emission scenarios, the current summary may be able to give decision-makers useful information on rainfall and temperature trends over Indian river basins. In addition, a review of prior studies aids researchers in identifying climate change-related research questions.

FUTURE SCOPE

To increase the reliability of forecasts, climate models must be continuously improved, especially in the modelling of land-surface processes. Future study should be helpful in extending the number of climate models in an ensemble modelling approach, as it is generally acknowledged that the GCM structure is the main source of uncertainty (Kay *et al*. 2009). Despite the fact that many research have acknowledged the necessity for various climate models, the majority of studies only use one hydrological model and a downscaling/bias correction approach.

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Conflicts of Interest. None.

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