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Climate Change Impacts on Hydrology and Water Resources of Indian River Basins

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Abstract

Anthropogenic greenhouse gas emission is altering the global hydrological cycle due to change in rainfall pattern and rising temperature which is responsible for alteration in the physical characteristics of the river basin, melting of ice, drought, flood, extreme weather events and alteration in groundwater recharge. This study reviewed that about 40% of Arctic sea ice has melted just within 40-50 years and global mean sea level has risen up to ~0.09 to 0.88 meter as a result of global climate change. Furthermore, climate change has induced the surface temperature of the Indian subcontinent by 0.48 ^{0}C in just last century. Additionally, various mega-deltas of world particularly Ganges-Brahmaputra-Meghna in Bangladesh, the Mekong in Vietnam and the Nile in Egypt are most vulnerable deltas in context of global climate change. Approximately, one million people of these mega-deltas could be affected by 2050 as a result of sea level rise, coastal erosion, land loss and flooding.Ganges–Brahmaputra–Meghna (GBM) river basins have great importance for their exceptional hydro-geological settings and deltaic floodplain wetland ecosystems which support 700 million people in Asia. The climatic variability like alterations in precipitation and temperature over GBM river basins has been observed which signifies the GBM as one of the most vulnerable areas in the world under the potential impact of climate change.In India, climate change is likely to impact on various freshwater resources like Ganga, Mahi, Tapi, Krishna, Pennar, Cauvery, Kachchh, and Kathiawar. These river basins experienced minimal per capita water availability mainly due to alterations in precipitation and temperature. Consequently, alteration in river discharge, higher runoff generation, low groundwater recharge and melting of glaciers over river basins could be observed shortly. The consequence of these changes due to climate change over river basins may create serious water problem for Indian sub-continent. This paper reviews the literature on the historical climate variations and how climate change affects the hydrological characteristics of different river basins.

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Introduction

In the last few decades, increased level of carbon dioxide and radiative trace gases in the atmosphere has been observed which induce the climate change and greenhouse warming to the world[1]. The global average surface temperature has increased significantly in last 100 years. The projection of many studies has confirmed that in next 100 years the earth will experience with high surface temperature[2]. In the present scenario, various environmental components such as physical and biological systems in different continents are severely affected by recent climatechange(Fig. 1)[3].Several studies around the world confirm that anthropogenic greenhouse gas emission is changing the average global temperatures (increased about 0.6 ^{0}C) which are altering the global hydrological cycle that affects almost every aspect of human life[1,4,5]. The hydrological cycle is an important component of the worldwide climate system which plays an essential role in the redistribution of sun's energy throughout the globe in the form of latent heat flux[6]. However, the modification in the global hydrological cycle due to climate change, drought, flood, changes in rainfall pattern, extreme weather events and alteration in river flow and groundwater recharge (Fig. 2) have been observed in various part of the world[7,8]. The consequences of climate change; sea level raised ~10 to 20 cm and ~40% of Arctic sea ice has melted just within 40-50 years. Also, since 1936 to 1999, the annual discharge of six largest Eurasian rivers has increased ~7% to the Arctic Ocean[3]. Some reports also showed that 4% global runoff increases by 1 °C global temperature rise[9].Consequently; global mean sea level has risen up to~0.09 to 0.88 meter since the start of the twentieth century[10].Additionally, climate change has already impacted on the various mega-deltas particularly due to sea-level rise and changes in runoff[3].It is estimated that around 300 million people live in the 40 mega-deltas globally. Ganges-Brahmaputra delta is having high population density (500 people/km^2) and one of themost densely populated deltas of the world[11].However, the mega-deltas including the Ganges-Brahmaputra in Bangladesh, the Mekong in Vietnam and the Nile in Egypt are most vulnerable deltas of world (Fig. 3)[3,12]. Some study also indicated that around one million people of these mega-deltas will be directly affected by 2050 due to sea level rise and coastal erosion, land loss and flooding[12].

In recent times, several studies in India have shown that climate change is likely to impact on freshwater resources by an alteration in rainfall pattern, rising surface temperature, changes in groundwater recharge, the timing of surface runoff and increased evaporation. The rising surface temperature of the Indian subcontinent by 0.48 ^{0}C has been observed over the last century[13].The alteration in the rainfall pattern has been observed in India where mean value of five year rainfall deviated from 6 to 15% than the normal rainfall pattern[14]. Furthermore, the deviations in annual mean surface runoff over the Indian subcontinent has also been observedand concluded that the estimated annual discharge would increase up to ~ 25% by 2080[15].These reports indicate that climate change has largely influenced the water resources of the Indian subcontinent. However, in developing country like India, water demand for various sectors such as domestic, industrial and agricultural uses, has already increased in last few decades[16]. In India, several major and minor rivers are the greatest strength of freshwater resources that fulfil the water demands for agriculture, domestic and industrial purposes[17]. The annual flow of Indian rivers is about 1880 km^3/year in which only 36% of the total flow is utilized to fulfil the water demands for agriculture, domestic and industrial purposes[18]. However, India holds ~17.5% of the total global population where per capita water availability was 1820 m^3/person/year in 2001[19].Consequently, the expansion of agricultural sectors, land use pattern, development of industrial and urban centers are modifying the hydrological cycle, resulting in the per capita water demand of 1341 and 1140 m^3/person/year by 2025 and 2050 respectively[20].These uncertainties show that India would develop into the water-stressed country in the recent future.Therefore, present study is based on the given expected changes due to climate change over the Indian River basins and has been reviewed with studying the topography of river basin, water availability, climatic and hydrological condition. In this study, we have tried to summarise the previous studies related to Ganges-Brahmaputra-Meghna (GBM) river basins keeping in view that how the climate has changed in these river basins in recent times.

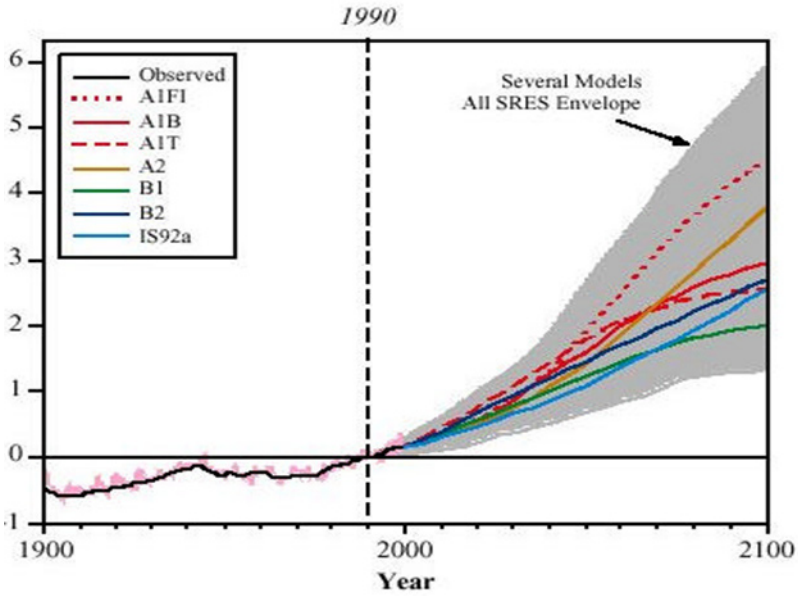

Fig. 1: Projection of the global mean temperature since 1900 to 2100 through different modeling frameworks[3]

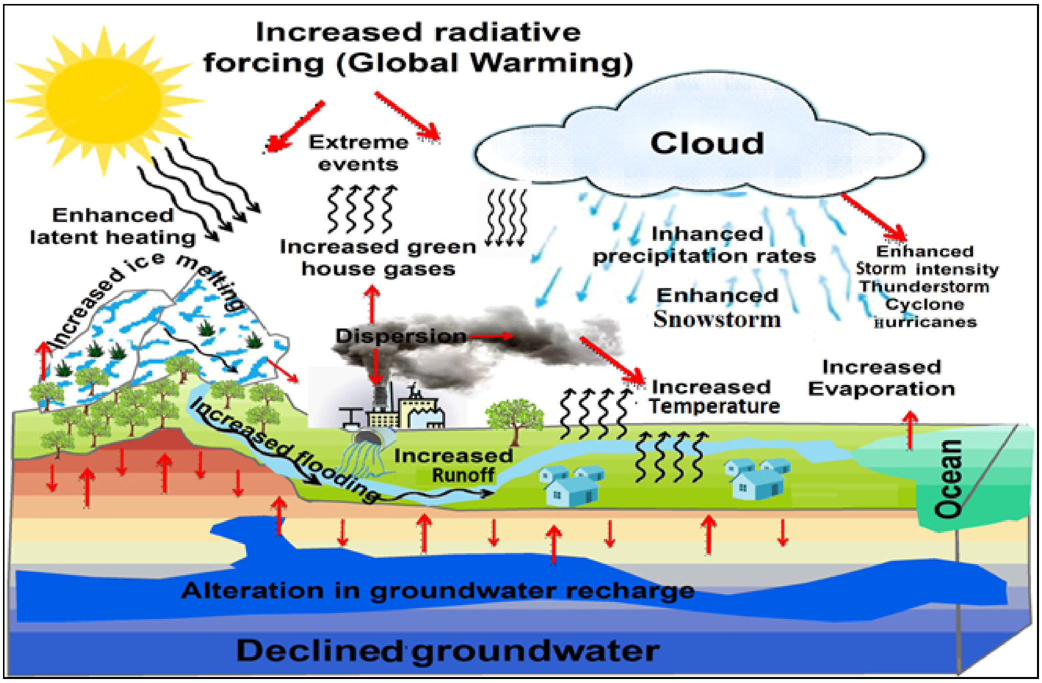

Fig. 2: Influences of global hydrological cycle in context of climate change

Fig. 3: The projection of relative vulnerability of coastal deltas by current sea level trends up to 2050 with three different classes viz. >1 million = Extreme; <1 million >50,000 = High and <50,000 to >5,000 = Medium[3,12]

Indian River Basin

In India, Himalayan range is the greatest source of pure water in the form of snow that melts and transverses through 45,000 km long riverine networks[21].There are thirteen major river basins (Fig. 4) in India which occupy around 83% of total drainage basin area with 85% of total surface flow and about 80% of Indian people reside in this area[22]. Also, twenty major rivers, and several minor rivers fulfil the water demands for agriculture, domestic and industrial purposes, which is greatest strength of Indian freshwater resource[17].Major river basins like the Indus, the Ganges and the Brahmaputra and their associated tributaries represent about 50% of India's fresh water resources[23].Presently, various Indian River basins like Ganga, Mahi, Tapi, Krishna, Pennar, Cauvery, Kachchh, and Kathiawar are under water stress condition due to over-exploitation and climate change (Fig. 2)[24]. These river basins have experienced a remarkable change in path, flow, water availability and reducing their self-natural purification capacity in last few decades[25].Additionally, various Indian river basins are experiencing with minimal per capita water availability which is mainly due to considerable spatial variation in rainfall[26].The consequence of these changes due to global climate changes and water needs may create serious problem including loss of biodiversity and aquatic system, local and regional water availability as well as humans from water shortage and flooding[27].

The Ganga River Basin

Ganga is the largest Indian river which extends between the latitude of 22^0 30'N to 31^0 30'N and the longitude of 73^0 0'E to 89^0 0'E (Fig. 5) and traverses a length of about 2550 km with a total catchment area of 1087300 km^2 in India and Nepal. The River originates from Gangotri glacier (Himalaya) at an elevation of 7010 m above mean sea level and drain through Indian states of Uttarakhand, Uttar Pradesh, Madhya Pradesh, Bihar, Jharkhand and West Bengal before submerging into the Bay of Bengal[28]. The Ganga plains are one of the most densely populated areas due to the availability of drinking water, fertile soil and suitable landscapes. Ganga River associated with some tributaries play an important role in the formation of most fertile alluvial plain. In the Gangetic plains, the area of Uttarakhand , Uttar Pradesh, Bihar and West Bengal represent a very large population of India. Nearly 670 million people and almost one-tenth of the world's population live in the plains of Ganga[29].

Many recent studies have examined the increasing trend in temperature, hydrological processes, ecosystems, and water resources due to effects of climate change in Ganga Basin. Shrestha *et al.,* (1999) reported that since 1978 to 1994, the temperature has increased 0.06 ^{0}C/year in Nepal region[30]. Furthermore, a study reported by Nepal (2012) revealed that the highest increase rate of temperature (0.05 ^{0}C/y) was observed in the Koshi region, a sub-basin of the Ganges[31]. The similar study has been done by Liu and Chen (2000) and they have found that the temperature has increased about 0.16 ^{0}C per decade between 1955 and 1996[32]. The maximum temperature trends have been observed in Nepal (Central Himalayan region)[30]. The projected future model showed that the annual temperature of this region would increase about 0.06 ^{0}C/y between 2000 and 2100[33]. However, Arora and Boer (2001)have reported that mean annual runoff of the River Ganga will increase about 5% by 2070 – 2100[34]. A similar study has been conducted by Miller *et al.,* (2012) which suggests that the River Ganga will become a seasonal river in recent future[35]. The annual precipitation over the Ganges Basin shows that monsoon precipitation has increased about 10 to 12.5%, especially in Koshi catchment[36,37]. Similarly, a study by Immerzeel *et al.,*(2010) showed that the precipitation had increased 8% especially in upstream of the Ganga Basin[38]. Overall, various projected data indicate that the monsoon precipitation might increase in the Ganga Basin in future.

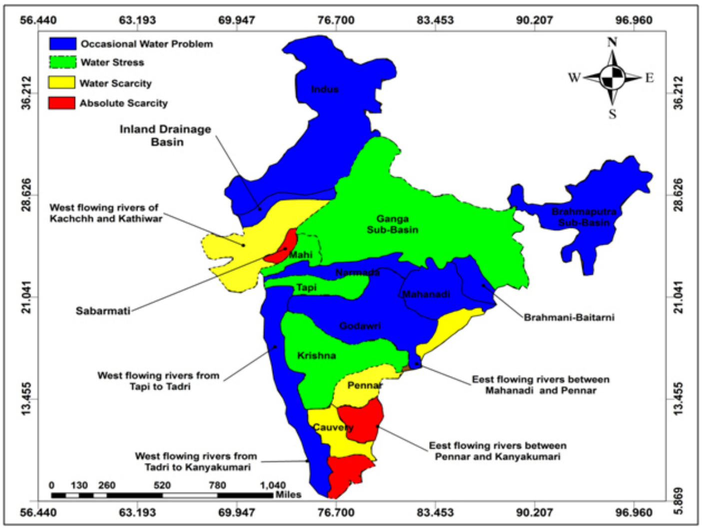

Fig. 4: Map of Indian major river basins in context of water availability

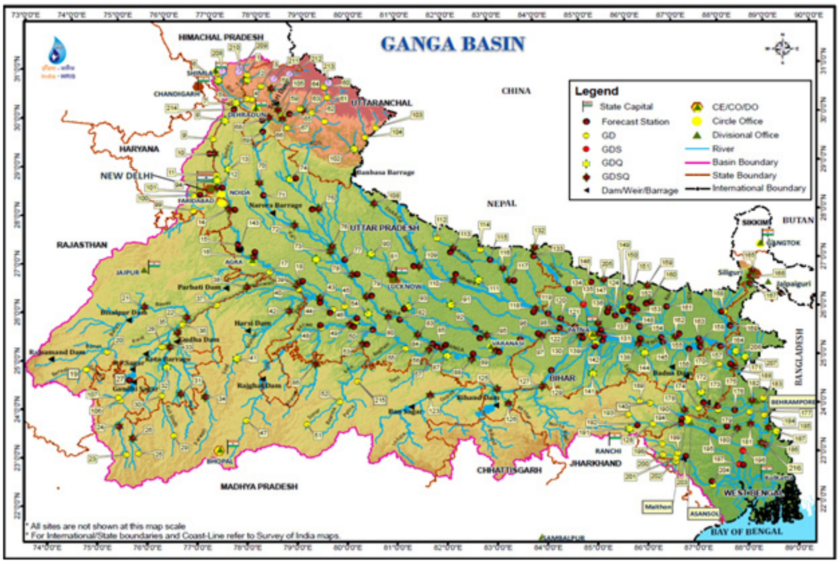

Fig. 5: Map of the Ganga River basin[69]

The Brahmaputra River Basin

The Brahmaputra River also originates from the Himalaya (Kailash ranges) which transverses east through the southern part of China and enter into eastern India and lastly joins with the River Ganga in Bangladesh[39]. In the journey, the river flows eastwards for 1130 km then enters in the Arunachal Pradesh followed by Assam and Meghalaya (India) for another 650 km and lastly enters Bangladesh (Fig. 6). The length of the Brahmaputra River is about 2840 km with having a total area of 5, 80,000 square kilometre[40]. The large portion of the river basin is covered with forest which is about 55.48% of the total area. In the upper part of Brahmaputra River discharge mostly comes from the snowmelt before it enters Arunachal Pradesh. However, after it enters into the Indian states of Arunachal Pradesh, Assam, and Meghalaya, river experiences with heavy rainfall which contributes substantially to the river flow. Consequently, river basin experiences with alteration in flow transport of sediment and channel configuration[41]. However, in the rainy season, floods are a common phenomenon in the plain areas of India due to heavy discharge of Brahmaputra River[42].

However, not many studies have been carried out in context of the vulnerability of climate change on Brahmaputra basin as compared to Ganga River basin[35]. Some previous studies revealed that the average annual temperature of Brahmaputra basin has increased notably in last few decades[43,44,45]. Flugel *et al.,* (2008) have observed that since 1961 to 2005, the average temperature of the upper Brahmaputra River basin has increased by 0.28 ⁰C per decade[43].Furthermore, the study by Immerzeel (2008) showed that the temperature had increased about 0.68 ⁰C per 100 years from 1900–2002, especially in the spring season[44]. The extensive physical assessment of the Brahmaputra River basin has been carried out by Mahanta *et al.,* (2014)[45]. The authors studied the possible climate change impacts on temperature, evapotranspiration, rainfall, and river flows in the basin. They expected that the temperature might increase from 1.3 ⁰C to 2.4 ⁰C by 2050, followed by 2.0 ⁰C to 4.5 ⁰C by 2100 in the Brahmaputra River basin. Similarly, they suspected that the monthly evapotranspiration is likely to increase 5% to 18% by 2050 followed by 7% to 36% by 2100. The alteration in average monthly rainfall has also been observed by researchers through a future projected model which suggests that the variation in rainfall to be 14% decrease to 15 % increase by 2050 and 28 % decrease to 22 % increase by 2100 respectively[45]. The overall result justified by authors showed that climate change might be responsible for the alteration in the physical characteristics of Brahmaputra River basin shortly.

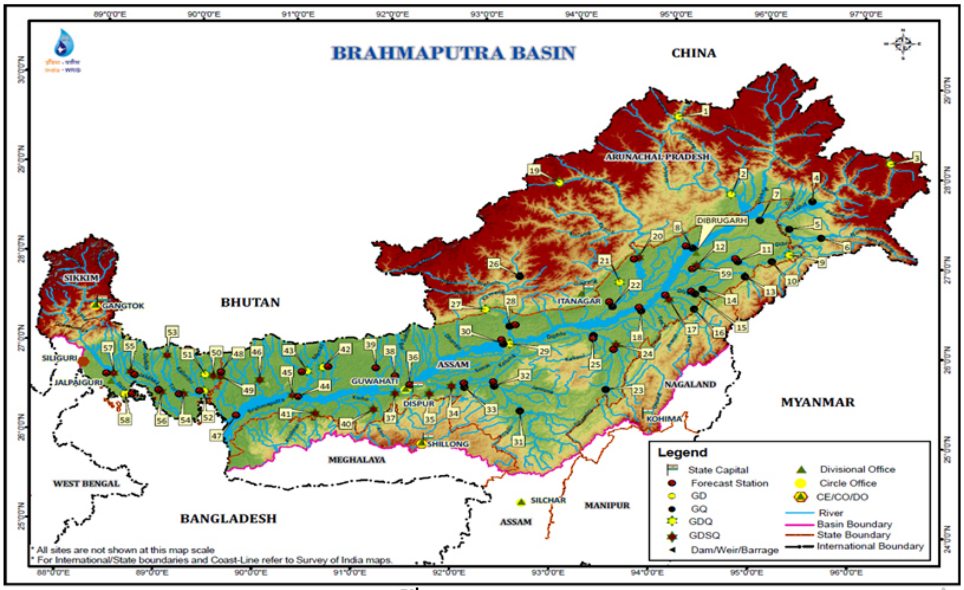

Fig. 6: Map of Brahmaputra River basin[70]

Impact of Climate Change on the Hydrological Regime of GBM System

India has a long riverine network system which mainly belongs to Himalayan river system and draining to the major plains of the country. The Ganga-Brahmaputra-Meghna (GBM) is the trans-boundary river basin which covers over 1.7 million Km^2. The total area of the GBM rivers distributed between five different countries which include India (63%), China (18%), Nepal (9%), Bangladesh (7%) and Bhutan (3%) and ultimately drain into the Bay of Bengal[46]. The headwaters of Ganges and Brahmaputra River originate in the Himalayan mountain range in China[47]. The Meghna originates from the Manipur hills, India and enter into Bangladesh associated with Surma and Kuchiyara Rivers. Subsequently, the Meghna joins with Ganges and Brahmaputra in the Chandpur and lastly drains into the Bay of Bengal[48].The GBM River basins support the lives and livelihoods of some 700 million people,and currently, basins have been widely utilized for drinking, irrigation, navigation, industry and hydropower generation purposes[49]. These basins extend across multiple countries, resulting river basins have experienced with different climate and flow regimes, influenced to a large extent by the summer and winter monsoons. The GBM delta is the second world largest delta which has spread over the Bengal basin of the South Asian region (Fig. 7) and third largest freshwater outlet to the world's oceans[50]. These rivers in the Bengal basin are spread over the coastal zone and offshore areas. However, these rivers carry an enormous amount of water and sediments (10^9t/year) which is responsible for forming and enlarging the Ganges delta[51]. The combined outfall of the GBM Rivers also plays an essential role including surface and groundwater recharge, reducing saltwater intrusion, and increasing soil fertility[52]. GBM basin flow is strongly influenced by the melt of snow. However, the temperature has increased in last few years, which has induced the rate of melting of glacial and snow. Consequently, summer flows of some river systems may increase followed by are duction in flows as the glaciers disappear and snow diminishes[38]. Also, some study also suspects that every populated basin in India such as Ganga-Brahmaputra-Meghna (GBM) is more vulnerable to water stress and alteration in river discharge.

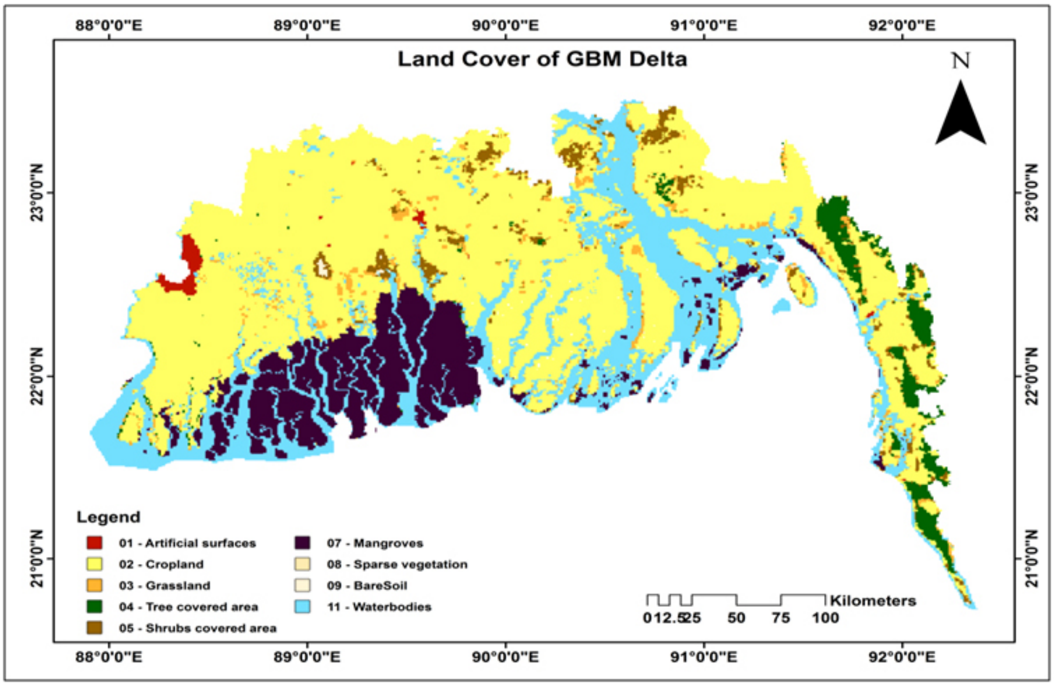

Fig. 7: Global Land Cover-SHARE of Ganges Brahmaputra Meghna Delta

However, some studies have revealed that climate change significantly affects the hydrology and water resources of the GBM basins which might be responsible for more severe floods and drought problem in recent time[53]. The climate change is already inducing the combined effect of glacier melt and extreme monsoon rainfall over the GBM river basins, which may be responsible for the rise of sea level[54]. The consequences of climate change over the GBM river basin includes more intense rains, alteration in the spatial and temporal distribution of rainfall, higher runoff, low groundwater recharge and changes in evaporative demands[55]. These impacts on GBM river basin could also influence the agricultural production, food security, and biodiversity as well as water security for Indian subcontinents[56]. The delta regions of GBM river basin in Bangladesh and India are particularly vulnerable to future climate change[57].

Shamsudduha *et al.,* (2009) observed that groundwater levels in the GBM delta had declined more than 1 m/yr continuously from 1985 to 2005[58]. Furthermore, Kamal *et al.,* (2013) have carried out the seasonal variability of monsoon and dry periods through projected data of the period of 2020s, 2050s, and 2080s. The results signify that the peak flow of GBM rivers may enhance about 4.5 - 39.1% in monsoon period while in the dry period, low flows may decline by 4.1- 26.9% which reveals high seasonal variability as a result of climate change[59]. Masood *et al.,* (2015) suspected that by the end of 21st-century entire GBM basin would be warmed by three degree celsius. Also, researchers have projected that the changes in mean precipitation more than 15.2 % and alteration in mean runoff more than 18% could occur in GBM River basin by the end of 21st century[60]. Similarly, Whitehead *et al.,* (2015) conducted the study on GBM River basin sbased on the future climate model for 2050s and the 2090s. The results indicate a significant increase in monsoon flow under the future climate with enhanced flood potential. Authors have also predicted the low flows and extended drought periods over GBM basin, which could impact on water and sediment supply, irrigated agriculture and saline intrusion[29].

Consequences of Climate Change over GBM Delta

The GBM delta is the second largest in the world which plays an important role in South East Asia to fulfil the needs of hundreds of millions of people, including many large and growing cities[61]. However, in the present scenario, physical environmental changes have been observed throughout GBM delta region due to climate change including several reservoir creations, dredging and channeling to control water availability. Also, high erosion during an extreme event like Sidr cyclone in 2007[62], a slightly less net gain of land in the Bangladesh part[45] and a net loss of land in Sundarban mangroves[63] have been observed in the last few decades. Furthermore, during the 20th century, the rate of sea level rise has significantly (0.07 inch/year) increased whereas the local sea-level rise of about 1 inch per year has been noted in GBM Delta[64]. Some studies also revealed that most of the deltaic plains of Ganges, Brahmaputra, and Meghna have an elevation of less than 16 feet[65]. Consequently, in coming years, people living on this delta may face the threat of rising sea levels[66]. This region could also experience severe flooding as a result of melting of snow and glaciers[67]. The previous studies estimated that rising of sea-level in the GBM delta could directly affect more than 3 million people and lose nearly one-quarter of the land area[66]. Similarly, disaster risks like high exposure to floods and droughts, reduction of sediment supply and alteration in water flow due to dams and abstractions in the GBM delta could increase in the next 15-30 years and might be responsible for the sinking of deltas. Consequences of these changes over GBM delta are also likely to face growing water stress in different countries *viz.* India, China, Bangladesh, Bhutan, Myanmar,and Nepal[68].

Conclusion

The review has provided information about the climate change and their consequences over the water resources. The previous studies mainly signify the changes in river flows, melting of ice, precipitation, and temperature through different models. Several studies have indicated that due to climate change, global temperature has increased significantly in last century and it will increase rapidly in next 100 years.In the present scenario, climate change has impacted on annual discharge of rivers, global runoff, global temperature, global mean sea level, and various mega-deltas.The mega-delta like Ganges-Brahmaputra-Meghna (GBM) delta is one of the most vulnerable deltas of world in context of climate change.The remarkable change in GBM basin climate is likely to have a significant impact on its rivers, which could enhance the flooding potential and drought problem. These impacts on GBM river basin could also influence the agricultural production, food security, and biodiversity as well as water security for Indian subcontinents.The situation may become worse if it is associated with global warming and accelerated sea level rise. However, the assessment of climate change impact on water resources is still subject to considerable uncertainty. Therefore, it is essential to get more details about the long-term observations of climate variables in water resources to improve regional climate models and the climate projections.

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