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STREAMFLOW ASSESSMENT IN CHANGING MONSOON CLIMATE IN TWO NEIGHBOURING RIVER BASINS OF EASTERN INDIA

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ABSTRACT

Sustainable water resources development and management has come up as unambiguous challenge for the water resources managers all over the world due to changing climate. The condition becomes more serious in the countries that host monsoon climates. The present study has been taken up to assess the climate change impact on stream flow of two neighboring river basins in Eastern India using delta climate change information of three general circulation models (GCMs): UKMO-HADCM3, MPIM-ECHAM5 and CSIRO-MK3; for three scenarios: A1B, A2 and B1; and three future time periods: 2010-39, 2040-69, 2070-99 with respect to the base period 1961-1990 using Arc SWAT model. These two river basins, Brahmani (38,648 km^2) and Baitarani (12,900 km^2), create common delta before falling into the Bay of Bengal and which has flood as a regular phenomenon. The modeling results show decreasing tendency of stream flow in Brahmani river basin whereas increasing tendency of streamflow in Baitarani river basin under the provided combinations of GCMs, scenarios and future time frames with respect to the base period in a remarkable manner during monsoon. Since, the results show different perspective of streamflow in neighboring river basins; it is of utmost importance for water resources manager to analyze the water resources of individual river basin for planning purpose.

Keywords: *Climate change, monsoon climate, water resources, sustainable, stream flow*

INTRODUCTION

Climate change impacts on water resources have received scientific attention over the last few decades due to the detrimental effects on hydrologic variables such as precipitation, streamflow, evapotranspiration and its significance on the surrounding ecosystems in global as well as regional scale (Frederick and Major, 1997; Xu and Singh, 2004; Juen et al., 2007; Xu et al., 2011). Fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007) states water as an important agent which delivers climate change impact on society in an adverse way through different sectors like energy, agriculture and transport. To address the issues requires knowledge of how hydrologic cycle is being affected by climatic change due to the critical physical links between the climate system and hydrological cycle (Mondal and Mujumdar, 2015). Inquiries of such knowledge have been the theme of many studies that investigated effects of climate change on hydrological cycle for various spatial and temporal scales for sustainable and practical water resources management (Aber et al., 1995; Strzepek and Yates, 1997; Yates, 1997; Arnell, 1999; Menzel, 2002; Matondo et al., 2004; Mooij et al., 2005; Gosain et al., 2006; Jha et al., 2006; Wilby and Harris, 2006; Hagg et al., 2007; Kingston et al., 2011; Anandhi et al., 2011; Gosain et al., 2011; Islam et al., 2012; Faramarzi et al., 2013; Gaur, 2013; Mitra and Mishra, 2014; Kulkarni et al., 2014). These studies were done on global or continental and regional scale (Aich et al., 2014). Global scale allows for a general view of the larger context and patterns, whereas regional scale allows the details of the studies. Few studies have reported that climate change is likely to lead to a major impact on regional water resources (Arnell, 1999; Lehner et al., 2006).

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Brahmani and Baitarani basins have been a primary agriculture center and now transforming into industrial hub at various locations. Historically, the majority of the flow in the basin has been allocated to different purposes without prior potential analysis. Both river basins fall within the sub-tropical monsoon climate zone (Mitra and Mishra, 2014). About 80% of the annual normal rainfall occurs during the 4 months of south-west monsoon season (June to September). The annual normal rainfall varies from 1250 mm to 1750 mm over the Brahmani basin and from 1250 mm to 1500mm over the Baitarani basin. The coefficient of variation of annual rainfall is only about 20%, which shows that the rainfall in the region is fairly dependable (Dahm et al., 2016). Variability of rainfall may increase due to possible impact of climate change. Geo-hydrology of the two basins makes it flood prone. These two basins have experienced serious floods during 2001, 2003, 2006, 2008, 2011 and 2013 (Government of Odisha, 2011; Government of Odisha, 2013) due to changes in monsoon rainfall (Dahm et al., 2016). Flood damages have particularly risen over the last decade, at a rate of 7% per annum over the period 2003 to 2011 in constant prices. Compared to the period 1980-93 the average annual damages nearly doubled for the period 1997-2012 (Government of Odisha, 2013). This is course a worrisome fact. Therefore it is important to assess the impact of future climate change on streamflow of these two basins.

Only few previous studies have evaluated impact of climate change on streamflow. For example, Gosain et al. (2006) analyzed the effects of climate change using daily weather data from a regional climate model along with a distributed hydrological model, namely Soil and Water Assessment Tool (SWAT). They conclude that under an increasing greenhouse gas scenario, Brahmani is predicted to face severe flood conditions, though it may not have water shortages. Mitra and Mishra (2014) investigated climate change impact on streamflow using SWAT model for Baitarani basin. The analysis shows that the water availability at the Baitarani river basin is expected to increase in future under linear increase in rainfall since historic and expected increasing rainfall trend persisting in future. Islam et al. (2012) impacts of climate change on streamflow of the Brahmani River basin were assessed using Precipitation Runoff Modeling System (PRMS) run under the platform of Modular Modeling System (MMS). The plausible hypothetical scenarios of rainfall and temperature changes were used to assess the sensitivity of streamflow to changed climatic condition. Simulation studies with temperature rise of 2 and 4°C indicated 6 and 11% decrease in annual streamflow, respectively. However, there is about 62% increase in annual streamflow under the combined effect of 4°C temperature. But none of the studies really focus on the effects of changing monsoon climatic condition on water resources.

So, in this study, we extend these existing studies and examine climate change effects on monsoonal streamflow in the Brahmani and Baitarani river basin in India. To assess climate change impact on streamflow during monsoon in Brahmani and Baitarani basins, the study has been carried out using delta climate change information of three GCMs (UKMO-HADCM3, MPIM-ECHAM5 and CSIRO-MK3) for the scenarios A1B, A2 and B1 and three future time periods: 2010-39, 2040-69, and 2070-99 with respect to the base period 1961-1990 on monthly basis using daily precipitation and temperature (maximum and minimum) data; since, in comparison to daily values monthly meteorological variable are better simulated by GCMs (Grotch and MacCracken, 1991; Huth, 1997). These GCMs have been chosen for this study due to data availability for the delta change technique, used scenarios and mentioned periods with respect to the base period. Another important reason for this selection is that in Brahmani and Baitarani river basins, climate change impact analysis with the mentioned combinations of GCMs, scenarios and future time frames is unique.

This paper is organized as follows. Section 2 presents overview of collected data, downscaling and hydrological modeling technique. In Section 3 main findings of the study have been presented. Main focus is on the projected streamflow due to changing monsoon climate in the basins, separately, to have future water resources scenarios for better water resources management in the flood prone delta area. Section 4 summarizes the conclusions and provides prospects for future work and practical applications in the study area.

MATERIALS AND METHOD

Study Area

The study has been performed in two interstate (spread across the states of Chhattisgarh, Jharkhand and Odisha) river basins of eastern India: Brahmani (38,648 km^2) and Baitarani (12,900 km^2) river basins which are bounded between 20° 28' N to 23° 35' N latitude and 83° 52' E to 87° 30' E longitude and between 20° 35' N to 22° 15' N latitude and 85° 10' E to 87° 03' E longitude, respectively (Fig. 1(a) and Fig. 1(b)). Both river basins come within sub-tropical monsoon climate zone with annual rainfall of approximately 1450 mm (Dahm et al., 2016). About 80% of the annual normal rainfall occurs during the four months of south-west (SW) monsoon (June to September). The co-efficient of variation of annual rainfall is only about 20%, which shows that the rainfall in the region is fairly dependable. Daily temperature varies from 5 ^{o}C to 47.5 ^{o}C. The elevation ranges from >750 m to approximately 10 m. The soils of this area vary from rich red loamy to gravely detritus.

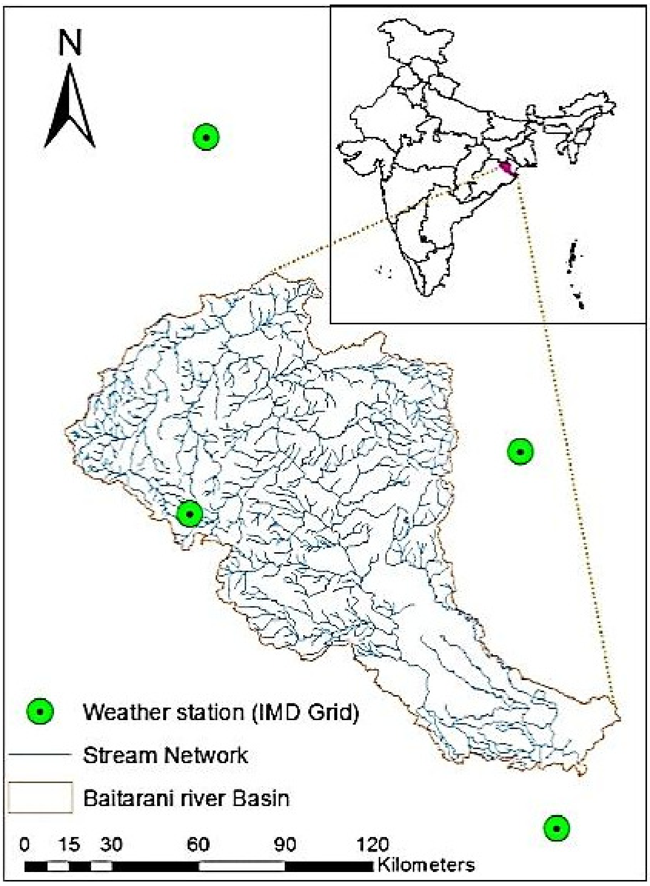

Fig. 1(a): Index map of Baitarani river basin, the study area.

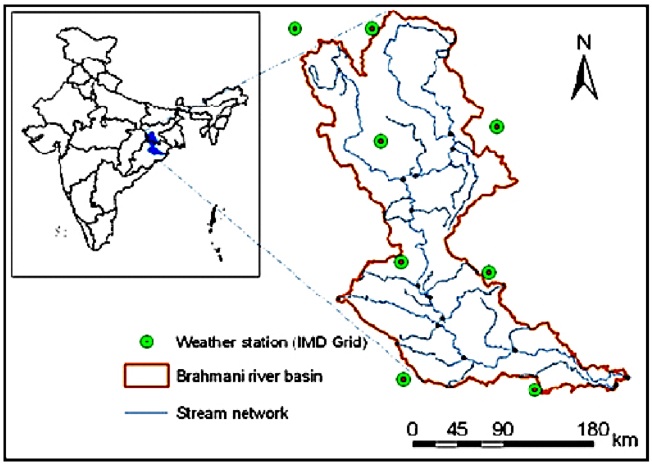

Fig. 1(b): Index map of Brahmani river basin, the study area.

Model Input

The input data for this study consist of daily rainfall, daily maximum and minimum air temperatures, digital elevation model (DEM), land use/land cover (LULC) and spatial soil information. Rainfall and temperature data of 19 grids of 1° x 1°, covering Brahmani and Baitarani river basins, have been collected from the India Meteorological Department **(IMD)** for the period 1961-2004. Four (G8, G13, G14, G19) of these grids are inside Baitarani river basin, and the rest 15 are inside the area of Brahmani river basin (Table 1). According to Dahm et al. (2016), monsoon (June to September) rainfall is projected to increase over Brahmani and Baitarani basins. It has also been deduced that the number of wet days are likely to increase in the monsoon season where changes are more pronounced towards the end of the century. The numbers of days of heavy rain are also likely to increase. The soil maps of Odisha, Jharkhand and Chhattisgarh were acquired from the National Bureau of Soil Survey & Land Use Planning **(NBSS & LUP)** in 1:2,50,000 scale and digitized in GIS to prepare model input. The **ETM$^+$** Landsat images were downloaded from the Global Land Cover Facility (GLCF) to prepare the LULC map of the basins. The Shuttle Radar Topography Mission **(SRTM) 90 m DEM** was downloaded from the Consultative Group for International Agriculture Research-Consortium for Spatial Information **(CGIAR-CSI)** to develop the topography of the basin. The change factor (CF) data have been collected from the IPCC website.

Table 1: IMD grid information over Brahmani and Baitarani river basin

Sl. No.	Grid ID	River Basin	Latitude	Longitude
1	G1	Brahmani	23.5	83.5
2	G2	Brahmani	23.5	84.5
3	G3	Brahmani	23.5	85.5
4	G4	Brahmani	23.5	86.5
5	G5	Brahmani	23.5	87.5
6	G6	Brahmani	22.5	83.5
7	G7	Brahmani	22.5	84.5
8	G8	Baitarani	22.5	85.5
9	G9	Brahmani	22.5	86.5
10	G10	Brahmani	22.5	87.5
11	G11	Brahmani	21.5	83.5
12	G12	Brahmani	21.5	84.5
13	G13	Baitarani	21.5	85.5
14	G14	Baitarani	21.5	86.5
15	G15	Brahmani	21.5	87.5
16	G16	Brahmani	20.5	83.5
17	G17	Brahmani	20.5	84.5
18	G18	Brahmani	20.5	85.5
19	G19	Baitarani	20.5	86.5

Hydrological Data

Measured daily stream flow data for the station named Jenapur (20° 55' 23" N latitude and 86 0' 51" E longitude) in Brahmani river basin and Anandpur (21° 19' 48" N latitude and 70° 30' E longitude) in Baitarani river basin, collected for the period 1974-2004 from the Central Water Commission **(CWC)**, are used for calibration and validation of the **ArcSWAT** model.

Description of ArcSWAT Model

Arc SWAT is a quasi-physically based continuous, long-term, distributed parameter model, developed jointly by the United States Department of Agriculture (USDA), Agricultural Research Service (ARS) and Agricultural Experiment Station Temple, Texas. The model uses input data of soil, topographic, LULC and meteorological data to simulate the hydrology of the study area. Model divides the study area into number of hydrological response units (HRUs) and the hydrological outputs are summarized on watershed/sub-basin wise to finally for a basin. The hydrology of the watershed is simulated by the model in two steps- the land phase and routing phase of the hydrologic cycle. The land phase controls the amount of water yield in each sub-basin and the routing phase controls the movement of water through the channel network of the watershed into the outlet.

Model Setup

The collected toposheets were georeferenced, mosaicked and were used for stream digitization. Soil maps were digitized into 96 classes of soils for Brahmani basin and 50 classes of soils for Baitarani basin. The area has been classified with supervised classification method and eight LULC classes namely water, evergreen forest, deciduous forest, mixed forest, unused land, orchard, urban and agriculture have been identified. The Hydrological Response Units (HRUs) were created by taking LULC, soil and slope factors as 5%, 5% and 5% respectively. Curve number method, Pennmann-Montheith method and Muskinghum method have been used for the calculation of surface runoff, potential evapotranspiration and channel routing respectively.

Calibration and Validation of ArcSWAT

Twenty six model process parameters for stream flow (Table 2) were considered for the sensitivity analysis in order to determine the major parameters controlling the stream flow measurement process in SWAT model. Sensitivity analysis of parameters has been performed according to Griensven et al. (2006). The parameters, ranked as - very important, important, slightly important and not important in the process of stream flow simulation (Table 3). Tuning very important and important parameters, model has been calibrated and validated precisely on monthly basis to set up the model for further analysis

Calibration and validation periods for stream flow at Jenapur gauging station for Brahmani river basin are 18 years (1980-1988) and 8 years (1996-2004), respectively. Calibration and validation periods for stream flow at Anandpur gauging station for Baitarani river basin are 14 years (1980-1994) and 9 years (1995-2004), respectively. Coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (E_{NS}) have been used to check the statistical performance of model calibration and validation.

Delta Change Input Chain (DCIC)

Fig. 3 depicts the DCIC scheme of this study. Here, climate change projections have been developed by using the delta change projections of GCMs (UKMO-HADCM3, MPIM-ECHAM5 and CSIRO-MK3) output for CC scenarios (A1B, A2, B1). The CF was then incorporated in the observed weather data of base period following the alpha change downscaling method (Diaz-Nieto and Wilby, 2005) to allow its use at the basin scale for 2010-2039, 2040-2069 and 2070-2099. This approach is applied differently for temperature (minimum and maximum) and precipitation data. Monthly variables from GCMs are used to modify the daily time series

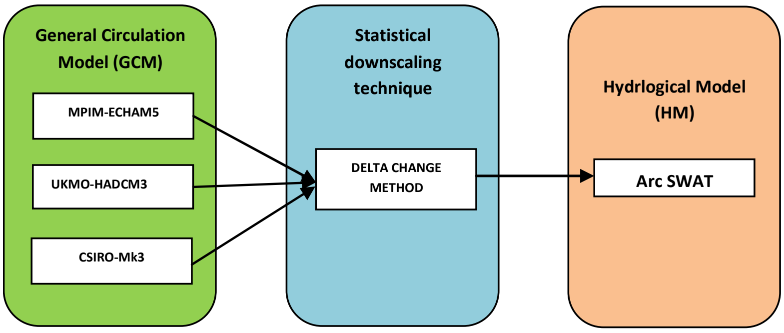

Fig. 2: Modeling chain for the climate change impact analysis.

Table 2: List of stream flow parameters used in Arc SWAT model

Sl. No.	Parameter abbreviation	Description
1	Alpha_Bf	Base flow alpha factor
2	Blai	Maximum potential leaf area index
3	Biomix	Biological mixing efficiency
4	Canmx	Maximum canopy storage
5	Ch_K2	Channel effective hydraulic conductivity
6	Ch_N2	Manning's n value for the main channel
7	Cn2	Initial SCS runoff curve number for moisture condition II
8	Epco	Plant uptake compensation factor
9	Esco	Soil evaporation compensation factor
10	Gw_Delay	Ground water delay time
11	Gw_Revap	Ground water "revap" coefficient
12	Gwqmn	Threshold depth of water in the shallow aquifer required to occur return flow
13	Revapmn	Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur
14	Sftmp	Snowfall temperature
15	Slope	Average slope steepness
16	Slsubbsn	Average slope length
17	Sol_Alb	Moist soil albedo
18	Sol_Awc	Soil available water capacity
19	Sol_K	Saturated hydraulic conductivity
20	Sol_Z	Soil depth from surface to bottom of the layer
21	Smfmn	Melt factor for snow on December 21st
22	Smfmx	Melt factor for snow on June 21st
23	Smtmp	Snow melt base temperature
24	Surlag	Surface runoff lag coefficient
25	Timp	Snowpack temperature lag factor
26	Tlaps	Temperature laps rate

Table 3: Rank of stream flow parameters

Sl No.	RANK	PARAMETERS		SENSITIVITY CATEGORY
		Brahmani	Baitarani	
1	1	Cn2	Ch_K2	Very important
2	2	Ch_K2	Surlag	Important
3	3	Surlag	Ch_N2	
4	4	Gw_Revap	Cn2	
5	5	Gw_Delay	Slsubbsn	
6	6	Ch_N2	Slope	
7	7	Alpha_Bf	Gwqmn	Slightly important
8	8	Esco	Alpha_Bf	
9	9	Slsubbsn	Canmx	
10	10	Slope	Sol_Awc	
11	11	Sol_Awc	Sol_K	
12	12	Sol_K	Timp	
13	13	Sol_Z	Gw_Revap	
14	14	Gwqmn	Sol_Z	
15	15	Canmx	Gw_Delay	
16	16	Sol_Alb	Esco	
17	17	Biomix	Sol_Alb	
18	18	Epco	Biomix	
19	19	Revapmn	Epco	
20	20	Timp	Revapmn	
21	21	Tlaps	Tlaps	
22	22	Blai	Smfmn	
23	23	Smfmn	Smfmx	
24	24	Smfmx	Sftmp	
25	25	Sftmp	Blai	
26	26	Smtmp	Smtmp	

needed for hydrological modeling. ArcSWAT facilitates the analysis of CCI by a provision of incorporating the change in weather variables into it. Description of delta change technique has been given below.

Delta Change Technique

The delta change technique (Diaz-Nieto and Wilby, 2005) is incorporated in the observed data for precipitation and temperature (maximum and minimum) of base period to allow its use at the basin scale for 2010-2039, 2040-2069 and 2070-2099. This approach is applied differently for precipitation and temperature (minimum and maximum) data. Monthly variables from GCMs are used to modify the daily time series needed for hydrological modeling. Equations for change factors for temperature and precipitation data are given as below.

$$P_F = P_O + P_O \times (P_{C.F.}\%) \quad (1)$$

$$T_{C.F} = T_F + T_O \quad (2)$$

Where, C.F., F, and O stand for change factor of delta change technique, future data and observed data, respectively. The monthly delta values obtained from Eqs. (1) and (2) were then applied to the daily observed historical data (precipitation and temperature) to develop future weather sequences.

RESULTS AND DISCUSSION

Calibration and Validation

In Brahmani basin for calibration, R^2 and E_{NS} are 0.75 and 0.73 respectively and for validation R^2 and E_{NS} are 0.84 and 0.80 respectively. In Baitarani for calibration R^2 and E_{NS} are 0.85 and 0.84 respectively and for validation R^2 and E_{NS} are 0.71 and 0.71 respectively. Moriasi et al. (2007) suggested that model simulations will be satisfactory if R^2 and E_{NS} are above 0.5 and difference between these two is not more than 0.05. According to these criteria it can be inferred that the model set up is satisfactory to simulate under present and future conditions for further analysis.

Precipitation, Temperature and Stream Flow Projections

The assessment of the future monsoonal streamflow for the two basins projects varying results (Figs. 3 and 4) with a tendency for decreasing streamflow in Brahmani basin and increasing streamflow in Baitarani basin as a mean overall projections of monsoon period for particular GCM, scenario and time period (Tables 4 and 5).

Increasing tendency is there for monsoonal temperature for the basin over the time frames for all combinations. Monsoonal precipitation in Brahmani river basin projects increasing tendency with respect to BP except the instances for [CSIRO-MK3 (A2)] for 2010-39 and 2040-69 as well as for [CSIRO-MK3 (B1)] for 2010-39 i.e., here it predicts a decrease in precipitation (Table 4). This can be due to the structure of CSIRO-MK3 and the scenarios A2 and B1. For three future time frames (in the ascending order) the precipitation is also increasing from one to another except the instances for [UKMO-HADCM3 (A2)] and [UKMO-HADCM3 (B1)] between 2040-69 and 2070-99 in both the cases, (Table 4). The changes in precipitation range from –

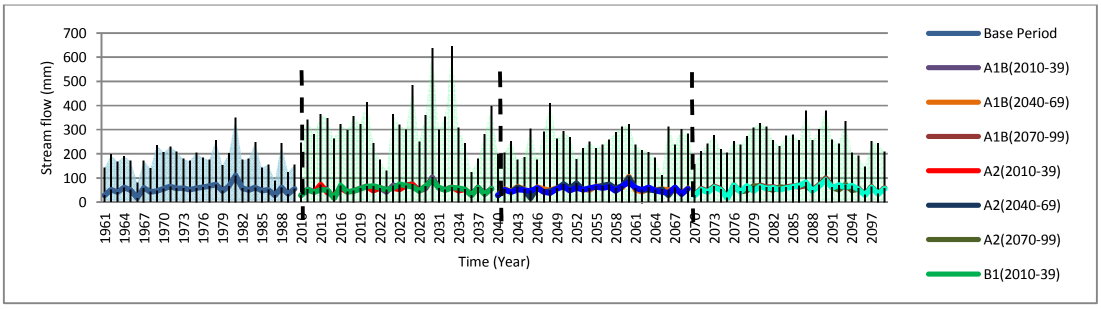

Fig. 3(a): Changes in streamflow for UKMO-HADCM3, all the scenarios and time frames in Brahmani river basin.

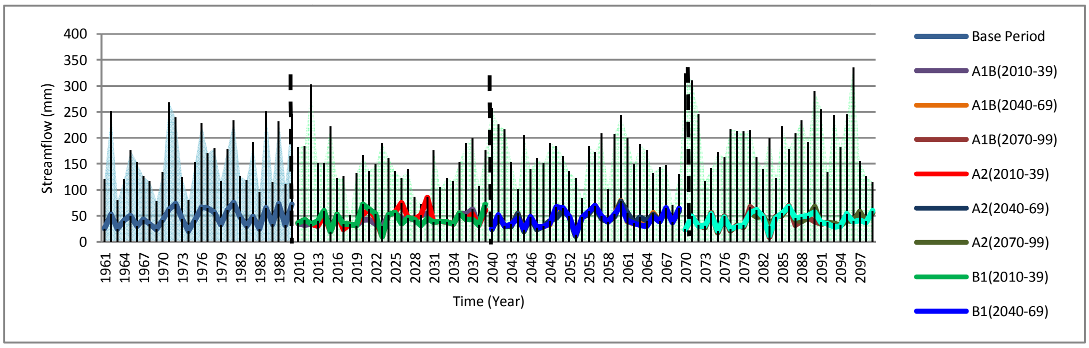

Fig. 3(b): Changes in streamflow for MPIM-ECHAM5, all the scenarios and time frames in Brahmani river basin.

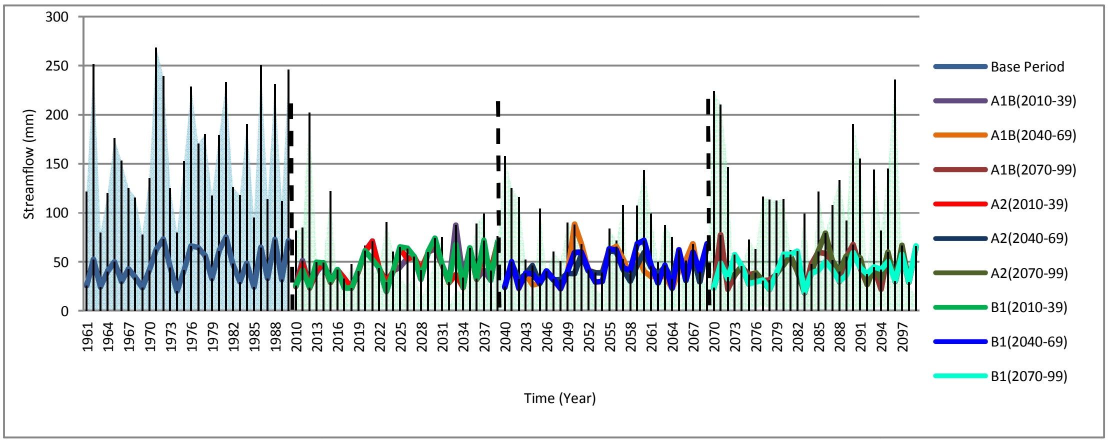

Fig. 3(c): Changes in streamflow for CSIRO-MK3, all the scenarios and time frames in Brahmani river basin.

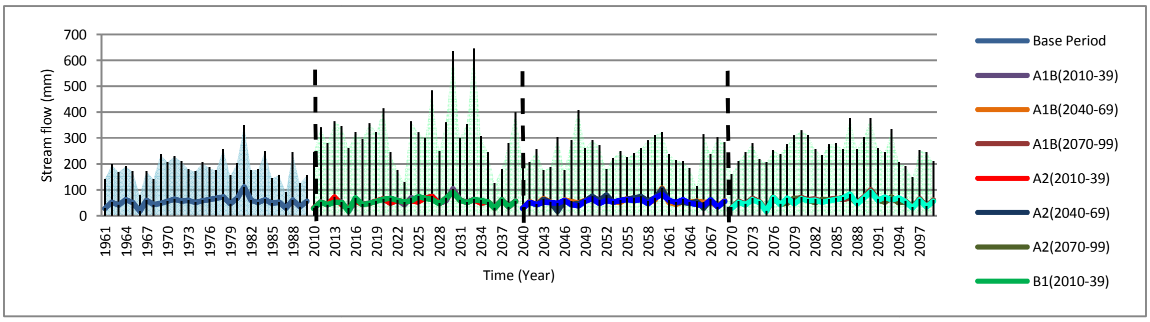

Fig. 4(a): Changes in streamflow for UKMO-HADCM3, all the scenarios and time frames in Baitarani river basin.

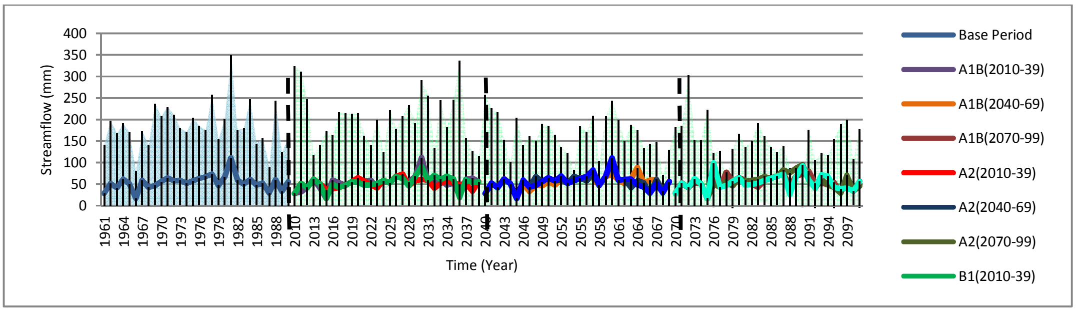

Fig. 4(b): Changes in streamflow for MPIM-ECHAM5, all the scenarios and time frames in Baitarani river basin.

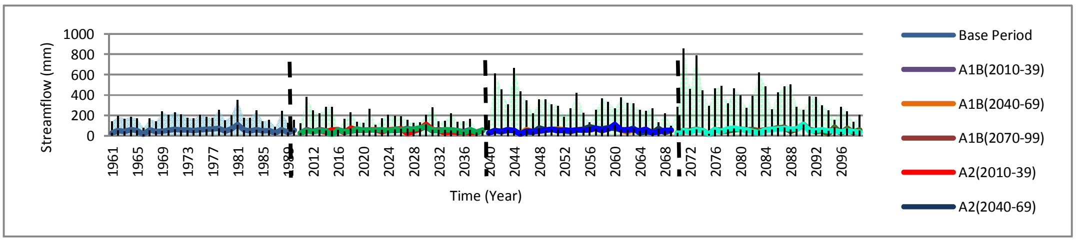

Fig. 4(c): Changes in streamflow for CSIRO-MK3, all the scenarios and time frames in Baitarani river basin.

Table 4: Changes in average annual mean precipitation, temperature and stream flow for all climate projections compared to the base period (1961-1990). Results are for 2010-2039, 2040-2069, and 2070-99 for Brahmani river basin during monsoon period

GCMs	GHGES	Precipitation (%)	Tmean (^{0}C)	Stream flow (%)
		A1B		
UKMO-HADCM3	2010-2039	0.58	0.54	-1.29
	2040-2069	1.12	1.99	-2.02
	2070-2099	1.16	3.47	-4.23
MPIM-ECHAM5	2010-2039	0.32	0.99	-1.25
	2040-2069	1.09	2.09	-2.55
	2070-2099	1.63	3.80	-8.40
CSIRO-MK3	2010-2039	0.02	0.79	-1.49
	2040-2069	0.65	1.68	-2.65
	2070-2099	0.77	3.00	-5.28
		A2		
UKMO-HADCM3	2010-2039	0.68	0.50	-1.20
	2040-2069	0.51	1.95	-2.12
	2070-2099	1.28	3.54	-2.67
MPIM-ECHAM5	2010-2039	0.46	0.82	-0.94
	2040-2069	0.69	1.73	-2.15
	2070-2099	1.55	3.75	-5.04
CSIRO-MK3	2010-2039	-0.095	1.36	-1.11
	2040-2069	-0.015	2.45	-2.36
	2070-2099	0.88	3.76	-4.21
		B1		
UKMO-HADCM3	2010-2039	0.40	0.81	-1.62
	2040-2069	1.16	0.87	-2.55
	2070-2099	0.65	2.46	-4.42
MPIM-ECHAM5	2010-2039	0.16	0.53	-1.60
	2040-2069	0.96	1.61	-3.10
	2070-2099	0.93	2.70	-6.81
CSIRO-MK3	2010-2039	-0.32	0.79	-1.66
	2040-2069	0.029	1.43	-3.09
	2070-2099	0.68	1.72	-5.04

Table 5: Changes in average annual mean precipitation, temperature and stream flow for all climate projections compared to the base period (1961-1990). Results are for 2010-2039, 2040-2069, and 2070-99 for Baitarani river basin

GCMs	GHGES	Precipitation (%)	Tmean (oC)	Stream flow (%)
A1B				
UKMO-HADCM3	2010-2039	0.27	0.99	1.07
	2040-2069	0.38	2.43	3.76
	2070-2099	0.46	3.82	6.67
MPIM-ECHAM5	2010-2039	0.13	0.94	0.94
	2040-2069	0.42	2.30	2.88
	2070-2099	0.53	4.00	2.55
CSIRO-MK3	2010-2039	-0.02	0.74	0.72
	2040-2069	0.19	1.66	1.75
	2070-2099	0.31	2.79	2.57
A2				
UKMO-HADCM3	2010-2039	0.29	0.9	1.31
	2040-2069	0.23	2.49	2.86
	2070-2099	0.44	4.43	4.18
MPIM-ECHAM5	2010-2039	0.16	0.69	0.85
	2040-2069	0.26	1.74	2.30
	2070-2099	0.53	3.96	2.60
CSIRO-MK3	2010-2039	0.20	1.17	0.94
	2040-2069	0.51	2.02	1.38
	2070-2099	0.21	3.55	4.06
B1				
UKMO-HADCM3	2010-2039	0.16	1.05	1.42
	2040-2069	0.35	1.78	3.63
	2070-2099	0.33	2.73	4.89
MPIM-ECHAM5	2010-2039	0.08	0.60	0.49
	2040-2069	0.40	1.6	0.63
	2070-2099	0.32	2.69	0.78
CSIRO-MK3	2010-2039	-0.12	0.71	0.80
	2040-2069	0.07	1.33	1.86
	2070-2099	0.23	1.76	2.81

1.54% to 162.54%, depending on the particular scenario and time frame. The monsoonal streamflow changes range from -1.25% to -8.40% in A1B, -0.94% to -5.04% for A2 and -1.6% to -5.04% in B1 for particular GCM and time period (Table 4). In spite of considerable increase in precipitation streamflow reduces. Retention of precipitation through soil moisture storage through infiltration, reduced amount of baseflow contribution due to lower level of water table and excessive evapotranspiration due to increase in temperature can be the possible reasons. A study of Ministry of Environment and Forest (MOEF) in 2004 [Now the name is Ministry of Environment and Climate Change] also concluded that due to increase in temperature or change in rainfall distribution in time, the increase in rainfall due to changing climate does not result in an increase in the stream flow, always. For 2070-99, the decrease in streamflow is more pronounced [Figs. 3(a), 3(b) and 3(c) and Table 4]. This suggests that the change will be more significant by 2100 [(Table 4) and (Figs. 3(a), 3(b) and 3(c))].

Increasing tendency is there for monsoonal temperature for the basin over the time frames for all combinations. Monsoonal precipitation in Baitarani river basin also projects increasing tendency for all combinations of the three future time periods from BP except the instances for [CSIRO-MK3 (A1B)] and [CSIRO-MK3 (B1)] for 2010-39 time frame i.e., here it predicts an decrease in precipitation (Table 5). For three future time frames (in the ascending order) precipitation is also increasing from one to another for the scenario A1B (for all GCMs), A2 (MPIM-ECHAM5) and B1 (CSIRO-MK3) (Table 5). For [MPIM-ECHAM5 (A2)] and [CSIRO-MK3 (A2)] as well as [UKMO-HADCM3 (B1)] and [MPIM-ECHAM5 (B1)] precipitation is increasing from 2010-39 to 2040-69 and then is decreasing for 2070-99 (Table 5). For [UKMO-HADCM3 (A2)] precipitation is decreasing from 2010-39 to 2040-69 and then increasing for 2070-99 (Table 5). The changes in precipitation range from -2% to 53%, depending on the particular scenario and time period (Table 5). The monsoonal streamflow changes range from 0.72% to 6.67% in A1B, 0.85% to 4.18% for A2 and 0.49% to 4.89% in B1 (Table 5). For 2070-99, the increase in streamflow is more pronounced (Figs. 4(a), 4(b) and 4(c)). This suggests that the change will be more significant by 2100 [(Table 5) and (Figs. 4(a), 4(b) and 4(c))]. The results suggest that it is important for planners to keep in mind the monsoonal changes when devising any water management strategies for the future.

CONCLUSION

This study assesses the CCI on streamflow in the Brahmani and Baitarani river basins in India with multi-climate models and multi-emission scenarios approach. The delta change method is used as a downscaling technique to generate future precipitation and temperature. Arc SWAT hydrological model has been set up, calibrated and validated to simulate the historical and future (due to eventual climate change) streamflow in the basins. Results of the analysis indicate that streamflow of Brahmani has decreasing tendency whether Baitarani has increasing tendency during monsoon period. But this is only possibility and may not happen which leads to uncertainty. Despite the uncertainty, it has to be noted that projections of hydrological changes in the two neighboring basins are highly related with the direction of the projected precipitation and temperature. Since, streamflow from both the basins effect the flood in the common delta, the study will be helpful for the water resources managers and planners in sustainable water resources management.

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