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Analysis of Trends in Temperature and Precipitation and its Impact on Hydrology of a Coastal River Basin in Eastern India

SHIVAM GUPTA[1]* and UTKARSH GUPTA[2]

[1]Central Agricultural University, Imphal - 795 004, Manipur, India
[2]Chandra Shekhar Azad University of Agriculture and Technology, Kanpur - 208 002, Uttar Pradesh, India

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Temperature and precipitation are the main components of the hydrologic cycle which is affected by the climate change phenomena. Coastal river systems are affected severely by the change in sea surface temperature, coastal wind and other dominating factors in the region. This article focuses on the hydrological modeling of a coastal river basin in Eastern India named as Baitarani river and further trends in historical temperature and precipitation data were analyzed for assessment of the changes in magnitude of these climatic variables. Soil and water assessment tool (SWAT) hydrological model was selected for the hydrological modeling of the river basin with manual calibration process. Correlation coefficient for model calibration at monthly scale was found 0.89 whereas for the validation period it was found to be 0.78. Calibrated and validated hydrological model was further used for the projection of streamflow up to the year 2050 for RCP2.6 scenario. Projection of streamflow suggests a rise in discharge during the monsoon season which can be attributed to the increased rainfall under the influence of climate change. Trend analysis of precipitation and temperature suggests a statistically significant rise in summer temperature and monsoon precipitation which result in rising discharge in the river.

(***Key words:*** *Baitarani river, Climate change, Hydrological modeling, Trend analysis)*

The Intergovernmental Panel on Climate Change (IPCC) reported in its third assessment report about the rising temperature of the earth by 0.6°C in the previous century (IPCC, 2007), and this rising trend in temperature affects the different regions including hilly terrain to snow and glacier-fed regions and plain land to coastal regions in different ways. Indian sub-continent is surrounded by ocean from three sides, and thus possess a large coastal border which makes this sub-continent more vulnerable to the effect of a warming climate. Extreme climate events such as high-intensity rainfall, heat or cold waves and cyclones cause massive destruction in the coastal regions. Apart from the climatic challenges such as cyclone, heat wave and heavy precipitation, low land coastal regions are prone to saltwater intrusion and salinity problems due to rising sea level (Agarwala *et al*., 2003; Dasgupta and Meisner, 2009; Kabir *et al*., 2006).

Changing trend in precipitation causes severe challenge in coastal regions ranging from urban flood to the flood in plain regions causing loss of life and agriculture. Several studies have been conducted to analyze the trends in precipitation and temperature during the last centuries which state that the rising temperature in most of the part of the world is unequivocal (Karl *et al*., 1993). Duhan *et al*. (2013) analyzed the temperature series over Central India and found that increase in mean temperature in the winter season is higher as compared to the increase in temperature during the summer season. Shivam *et al*. (2017a) carried out a study on temperature trends over a Himalayan river basin and found out that summer temperatures are likely to increase in the basin and minimum temperature is increasing with higher magnitude than maximum temperature which causes change in diurnal variations range.

Soil and Water Assessment Tool (SWAT) is a physically-based hydrologic model effective for simulating the hydrological process and widely accepted throughout the globe (Neitsch *et al*., 2011). Singh *et al*. (2013) used the SWAT model for hydrological modeling of the Tungabhadra river catchment in eastern India and found the model performance suitable for the streamflow simulation. Gosain *et al*. (2005) carried out a water balance study over the Krishna river basin of

**Corresponding author:* E-mail: shivamiitg@gmail.com

Andhra Pradesh for assessment of the water yield and water management planning in the river basin. Gosain *et al*. (2006) projected the river discharge for two rivers of India for assessing the impact of climate change on river hydrology using GCM scenario dataset. Uniyal *et al*. (2015) applied the SWAT model on upper Baitarani river for calculating the water balance component of the river and used several combinations of temperature and precipitation changes in the basin for assessing the impact of climate change.

Singh and Goyal (2016) used CMIP5 RCP scenario datasets for assessment of the impact of climate change on precipitation extreme events over a Himalayan river basin and stated the rise in extreme precipitation events over the basin for extreme emission scenarios. Several studies have utilized CMIP5 dataset for assessment of the climate change on various climatic factors including temperature and precipitation (Shivam *et al*., 2017b; Song *et al*., 2015; Yurekli, 2015). The objectives of this study were to find out the trends in historical precipitation and temperature datasets and hydrological modeling of the Baitarani river to find out the changes in the streamflow in the river.

In this paper impact of climate change on temperature, precipitation and hydrology of a coastal river basin have been analyzed with the following objectives:

1) Trend analysis of historical climate data using Mann-Kendall test and Sen's slope estimator.
2) Projection of precipitation and temperature data using Global climate model (GCM) datasets for RCP2.6 emission scenario up to 2050.
3) Assessment of changes in hydrology of the river basin using the SWAT model.

MATERIALS AND METHODS

Study area and data

Baitarani river basin is a major river of Odisha state in the eastern part of India which originates from Gonashika or Guptganga hills in Odisha and travels almost 360 km in Odisha state and joins the Bay of Bengal. Baitarani river is a coastal river which faces frequent massive flood in monsoon season and causes loss of life and property. The basin lies between the latitude 22.0° - 22.5° N and longitude 85.0° - 86.5° E (Fig. 1).

More than 80% of the rainfall occurs in monsoon months with an annual rainfall of 1534 mm. The maximum temperature is observed during May month with a mean of 34°C and the mean minimum temperature is 11°C in the winter month of January. The major portion of the study area is comprised of forest and agriculture land uses, with some area under wasteland. Fig. 2a shows the land use land cover map taken from the MODIS Land Cover Institute (LCI) where the legends corresponds to the standard land use classes as defined by the MODIS LCI and shown in Table 1.

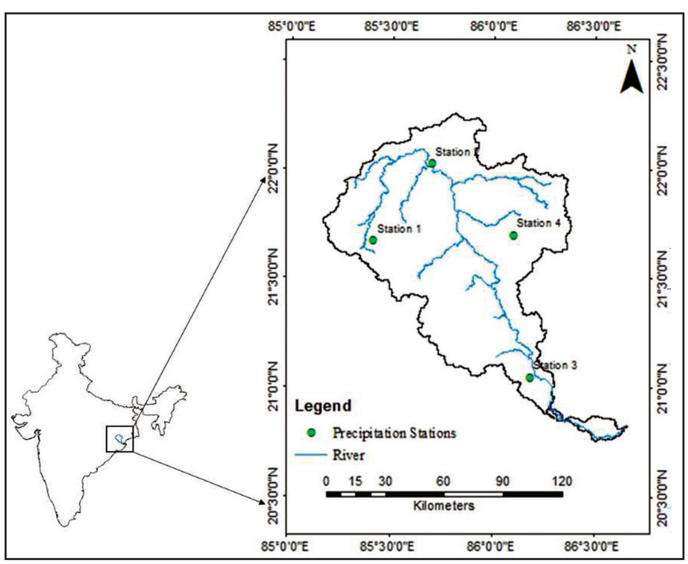

Fig. 1. *Baitarani river basin*

The study area has fertile alluvial deltaic soils in the northern part to black soils in the north-central plateau. Fig. 2b shows the soil map of Baitarani river basin and soil classes belongs to FAO Harmonized World Soil Database (HWSD) classified soil classes and their details are given in Table 2.

Temperature and precipitation datasets were taken from gridded datasets provided by India Meteorology Department (IMD) for the period 2000-2014. Discharge data was taken from the India Water Resources Information System (WRIS) website for the Jenapur discharge measurement site in Baitarani river basin for the period between 2004-2015 at monthly timescale. Food and Agricultural Organization (FAO) Harmonized World Soil Database (HWSD) soil map and MODIS Land Use Land Cover (LULC) dataset with 500 m spatial resolution was taken for the preparation of the SWAT model (Fig. 2). Global climate model (GCM) dataset was selected from the Geophysical Fluid Dynamics Laboratory (GFDL) for the low emission scenario of CMIP5 datasets which is termed as Representative Concentration Pathway scenario (RCP2.6) which has the spatial resolution of 2° X 2.5°.

Table 1. *Details of the land use and land cover classes in Baitarni river basin*

Legends	Soil class	Legends	Soil class
0	Waterbody	9	Savanna
2	Evergreen broad leaf forest	10	Grassland
4	Deciduous broad leaf forest	11	Permanent wetland
5	Mixed forest	12	Cropland
6	Close shrubland	13	Urban builtup
7	Open shrubland	14	Cropland and natural vegetation
8	Woody savanna	16	Barren or sparsly vegetated

Table 2. *Details of major soil types in Baitarni river basin*

Soil class	Major soil group	Topsoil texture	Bulk density (Mg m^{-3})
3729	Leptosols	Loam	1.20
3735	Lithosols	Loam	1.30
3791	Lixisols	Sandy Loam	1.53
3819	Nitisols	Loam	1.35
6663	Fluvisols	Loam	1.36
6667	Luvisols	Sansy Loam	1.51

Methodology

Hydrological modeling

Soil and water assessment tool (SWAT) model was used for the hydrological modeling of the Baitarani river basin. SWAT is a physical-based semi-distributed model which calculates the discharge using the formula of Soil Conservation Services (SCS) Curve Number (CN) method. Water balance equation calculated by the model is given as (Neitsch *et al*., 2011):

$$SW_t = SW_0 + \Sigma_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad \ldots(1)$$

where, for particular time t, SW_t = soil water content (mm), SW_o = initial soil water content (mm), R_{day} = amount of precipitation on time i (mm), Q_{surf} = amount of surface runoff (mm), E_a = amount of evapotranspiration on the i^{th} day (mm), W_{seep} = amount of water entering the vadose zone from the soil profile on the i^{th} day (mm) and Q_{gw} = amount of baseflow on the i^{th} day (mm).

SWAT model calculates the runoff using Soil Conservation Services Curve Number equation which is expressed as follows

$$Q = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \qquad \ldots(2)$$

Here, Q is the runoff generated in a particular day, R_{day}

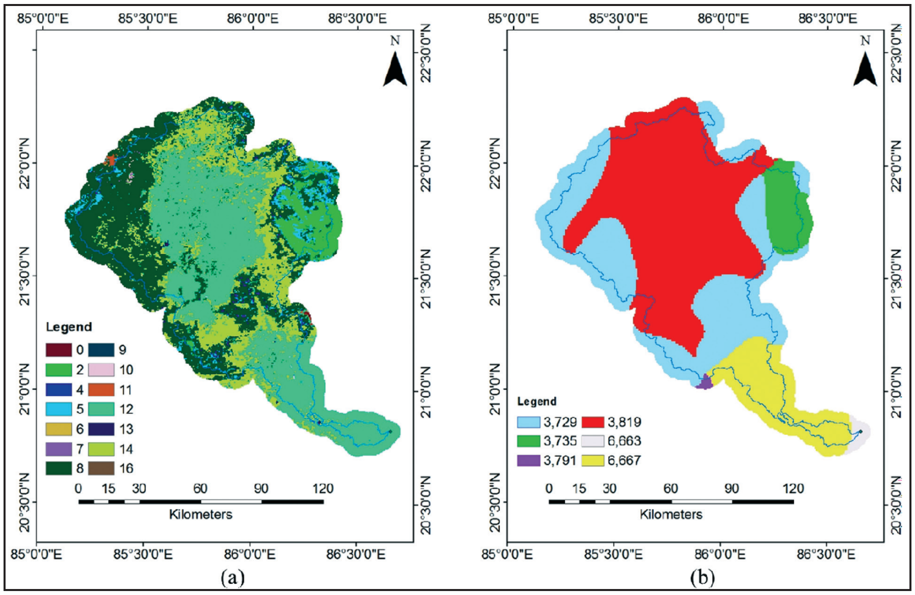

Fig. 2. *(a) Land use and land cover map and (b) soil map of the Baitarani river basin*

is rainfall for the day (mm) and S is specific retention. Runoff starts when rainfall for the day exceeds the 0.2S, specific retention (S) is attributed to the curve number (CN) which depends on the soil, land use land cover and antecedent moisture content. S can be represented as

$$S = 25.4 \times \left(\frac{1000}{CN} - 10\right) \qquad \ldots(3)$$

Model performance evaluation

Three model performance indices namely the coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) were calculated for the calibration and validation period.

Coefficient of determination (R^2): The coefficient of determination (R^2) is defined as the squared value of the coefficient of correlation which is calculated as:

$$R^2 = \frac{\Sigma_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\Sigma_{i=1}^{n}(O_i - \bar{O})^2} - \sqrt{\Sigma_{i=1}^{n}(P_i - \bar{P})^2}} \qquad \ldots(4)$$

where, O_i is observed data points, $\bar{O}$ mean of the observed data, P_i is projected data points $\bar{P}$ is the mean of projected data points, n is the number of data points in time-series.

Nash-Sutcliffe efficiency (NS): The Nash-Sutcliffe efficiency (NS) proposed by Nash and Sutcliffe (1970) is defined as one minus the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation. It is calculated as:

$$NS = 1 - \frac{\Sigma_{i=1}^{n}(O_i - P_i)^2}{\Sigma_{i=1}^{n}(O_i - \bar{O})^2} \qquad \cdots(5)$$

where, O_i is the observed value, P_i is the projected value and $\bar{O}$ is the mean of observed values.

Mann- Kendall trend analysis test

Mann-Kendall (MK) test (Kendall, 1975; Mann, 1945) is a non-parametric test which detects significance or non-significance of trends at specified confidence level. Pre-whitening of the data is required if autocorrelation exists in the series. The MK statistics (S) is calculated as

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i) \qquad \cdots(6)$$

where, N is the number of data points, assuming $(x_j - x_i) = \theta$, and the value of $sgn\ (\theta)$ is computed as follow:

$$\text{sgn}(\theta) = \begin{cases} 1 & if \quad \theta > 1 \\ 0 & if \quad \theta = 1 \\ -1 & if \quad \theta < 1 \end{cases}$$

This statistic represents the number of positive differences minus the number of negative differences for all the differences considered. The variance of the statistic S is calculated as

$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k(t_k-1)(2t_k+5)}{18} \quad \dots (7)$$

where, n and t_k are the number of tied groups and number of data points in the k^{th} tied group respectively. Mann-Kendall 'Z-statistic' is computed as

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \quad \dots (8)$$

Sen's slope estimator

Sen's estimator (Sen, 1968) is used to calculate the magnitude of change in data. Sen's slope can be calculated as

$$T_i = \frac{x_j - x_k}{j-k} \quad \dots (9)$$

where, x_j and x_k are data values; the median of these N values of T_i gives the Sen's estimator of the slope. Positive and negative values of T_i indicate increasing or decreasing trend respectively.

Bias correction

Bias correction of the GCM data was performed separately for temperature and precipitation as following

$$T_{db} = T_{proj} - (\overline{T_{cont}} - \overline{T_{obs}}) \quad \dots (10)$$

$$P_{db} = P_{proj} \times (\frac{\overline{P_{obs}}}{\overline{P_{cont}}}) \quad \dots (11)$$

where, T_{db} and P_{db} are the debiased temperature and precipitation series for the future time series and T_{proj} and P_{proj} are the projected temperature and precipitation series respectively. $\overline{T_{cont}}$ and $\overline{T_{obs}}$ are the controlled and observed temperature series respectively.

RESULTS AND DISCUSSION

Trend analysis of historical temperature and precipitation

For calculating the trends in precipitation pattern in the river basin, four precipitation indices were calculated *i.e.*, wet days in a year, annual precipitation, longest consecutive wet spell and longest consecutive dry spells. These indices were calculated with the threshold precipitation value of 1 mm per day which means that at any particular day if the rainfall is equal to or higher than 1 mm then it will be considered as wet day. Fig. 3 shows the boxplot of all four indices for selected four precipitation stations for 1951-2007. From the figure, it is observed that wets days in the region varies between 100-120 days in a year similarly annual precipitation varies between 1400-1600 mm. Consecutive wet days and dry days are the efficient indicators for the assessment of soil moisture condition for the vegetation and it is also a helpful indicator for drought assessment. Fig. 3 indicates that consecutive dry spell ranges between 50 to 60 days in the region whereas consecutive wet spell last for 10 to 15 days only.

Trend analysis of the temperature and precipitation were performed at monthly and seasonal timescale. Significance of existing trends in temperature was measured for summer and winter months whereas precipitation trends were measured for monsoon and non-monsoon months. Mann-Kendall Z (MK-Z) statistic of the summer months' time-series of temperature was found to be 3.1 which indicates statistically significant rising trends in the temperature at 95% confidence interval. Winter month temperature trend also shows an increasing trend but it was statistically non-significant. Table 3 represents the trend analysis results of temperature and precipitation at different timescale. MK-Z represents the Mann-Kendall Z statistics at 95% confidence interval, whereas Sen's slope represents the magnitude of change. Trends in diurnal variation of temperature showed no significant rising or decreasing trends.

Global climate model (GCM) rainfall and temperature datasets from GFDL were taken for the period from 2015-2050 for assessment of the changes in future temperature and precipitation in the region. GCM dataset was bias corrected before the assessment of changes following the method as explained in the methodology section. Average of the monsoon and non-monsoon month rainfall for the projected period of 2050 shows a rise in rainfall in the annual rainfall and monsoon rainfall, analysis of the wet days in projected scenario show decrease in wet days in a year which indicates increasing rainfall intensity in the region, which could cause the frequent flood situation in the basin.

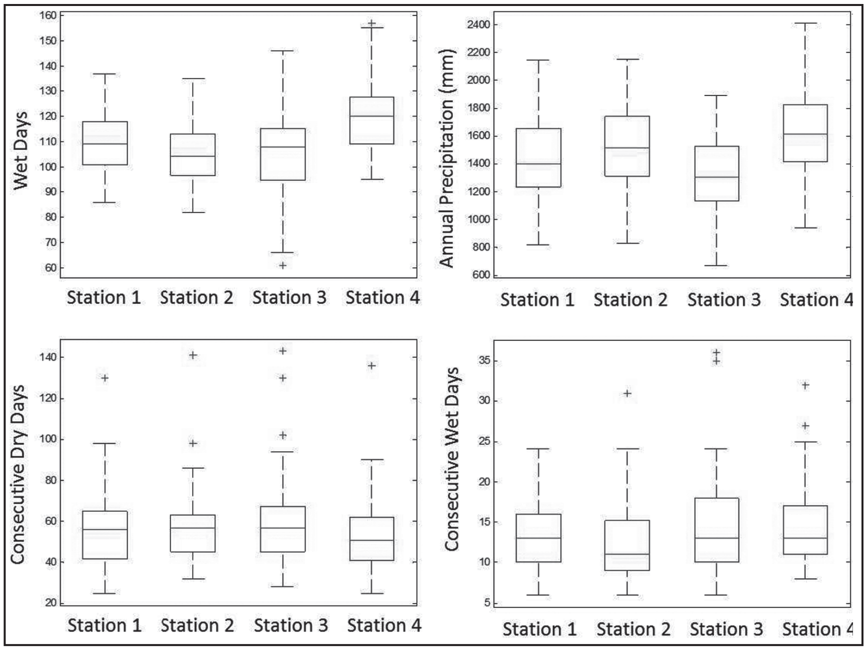

Fig. 3. *Boxplot of the wet days, annual precipitation, consecutive wet days and consecutive dry days in the selected weather station over the basin for the period of 1951-2007*

Hydrological modeling of Baitarani river basin

A hydrological model was prepared using the physical-based datasets e.g. soil map, LULC map and weather data such as precipitation and temperature. The model was calibrated by optimizing the parameter values. Bias corrected projected temperature and precipitation data series from the GCM dataset was used for projecting the streamflow using the calibrated SWAT model for the RCP2.6 climate change scenarios.

Hydrological modeling of the river basin was performed using the SWAT model which is a physical-based semi-distributed model. Land use-land cover map, soil map was taken from the sources as mentioned in the materials and methods section. Since the study area is dominated by plain land with less elevation variation, only two slope classes were assigned to the model. Weather data were taken from the IMD gridded datasets for precipitation and temperature. After setting the model input parameters, the model was calibrated for the period of 2000-2010 at monthly timescale. Model parameter optimizations were performed by manual calibration of the parameters and it was found that during the calibration period coefficient of correlation of model for streamflow simulation was found to be 0.89 (Fig. 4).

Model parameter sensitivity test was applied to find out the most sensitive parameters and further, sensitive parameter sets were used for the model calibration. Curve number, baseflow factor and soil hydraulic conductivity were found sensitive for the model and further model calibration was performed. After the calibration process, the model was run for validation for the period 2011-2015 and model performance was found satisfactory for the monthly timescale with a correlation coefficient of 0.78 (Fig. 5).

Table 4 shows the list of parameters which were selected for the model calibration for simulation of

Table 3. *Trend analysis results of temperature and precipitation*

	Tmean			Precipitation	
	MK-Z	Sen's Slope		MK-Z	Sen's Slope
Winter	2.19	0.17	Monsoon	2.87	5.2
Summer	3.1	0.19	Non-Monsoon	1.9	3.78
Diurnal Variation	1.7	1.43	Wet days	2.1	1

__Table 4.__ Calibrated model parameter values for streamflow simulation

Parameter	Full name	Calibrated values
r__CN2.mgt	Curve number	0.25
v__ALPHA_BF.gw	Base flow alfa factor	0.48
v__GW_DELAY.gw	Groundwater delay time	110
v__CH_N2.rte	Manning's roughness for main channel	0.1
r__CH_K2.rte	Soil hydraulic conductivity	0.2

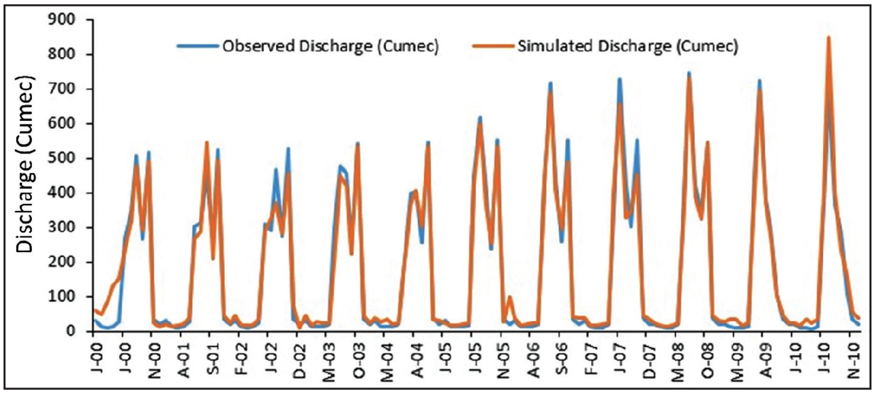

__Fig. 4.__ Observed and simulated streamflow during the model calibration period

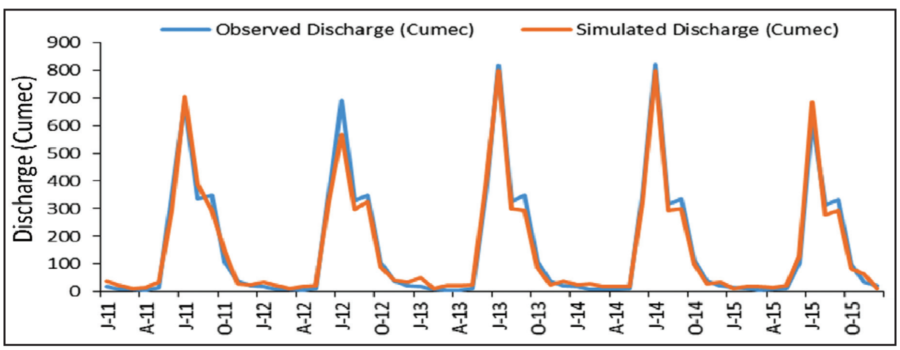

__Fig. 5.__ Observed and simulated streamflow during the model validation period

the streamflow. Curve number, base flow alfa factor, groundwater delay, Manning's coefficient for the main channel and soil hydraulic conductivity were found sensitive amongst the list of several parameters. The prefix r and v with the names of the parameters in Table 4, denotes the replace and value respectively which are the methods applied for changing the parameter values for iterations. Student's t-test and p-values were calculated for finding out the sensitive parameters and further manual calibration process was adopted for the parameter optimization.

Trend analysis of streamflow data

Baitarani river is a perennial river which originates in the Guptganga hills. The discharge in the river varies from as low as 10 cumecs in the non-monsoon season to as high as 700 cumecs during the monsoon season. A major portion of the rainfall occurs in the monsoon season only, therefore high discharge was observed in the river during the monsoon whereas in the non-monsoon season it decreases significantly, which has adverse effects on the local water supply for agriculture. Fig. 6 shows the trends of discharge in Baitarani river during the monsoon months and it was observed that only July month shows a significantly rising trend in discharge and other months show increasing or decreasing trends which are statistically non-significant at 95% confidence interval.

Flow duration curve of the monthly streamflow was plotted for assessment of the per cent of exceedance flow in the river. Fig. 7 shows the flow duration curve of Baitarani river for the monthly flows which exhibits that the maximum flow value of approximately 750 cumecs is available for 50% of the time in a year whereas low amount of flow is found for the entire year.

Projection of the temperature, precipitation and streamflow for the RCP2.6 scenario up to the year 2050 for the Baitarani river suggests a rise in summer temperature, monsoon rainfall and subsequently rise in river discharge which could be a challenge for the flood management in the region, whereas rising temperature can affect the seasonal water availability for agricultural and domestic water demands.

Projected temperature and precipitation time-series for the RCP2.6 emission scenarios upto the period of 2050 were used as the input in the calibrated hydrological model for the projection of the discharge in Baitarni river. Analysis of the projected streamflow shows the rise in monsoon season discharge which can be attributed to the increased monsoon precipitation in the projected emission scenario. Fig. 8 shows the comparison of the mean monthly discharge for the historical period (2000-2015) and projected discharge for the RCP2.6 scenario. It is evident from the figure that the increase in the discharge was higher in the monsoon season as compared to the non-monsoon month. For the month of June, the historical mean discharge was 326 $m^3 s^{-1}$ whereas for the projected scenario it increased to 376 $m^3 s^{-1}$. Similarly, for the months of July, August and September, the historical discharge was observed to be 605.32, 394.84 and 296.28 $m^3 s^{-1}$, respectively which increased to 650.13, 432.45 and 310.76 $m^3 s^{-1}$, respectively.

Apart from the physiological factors, temperature

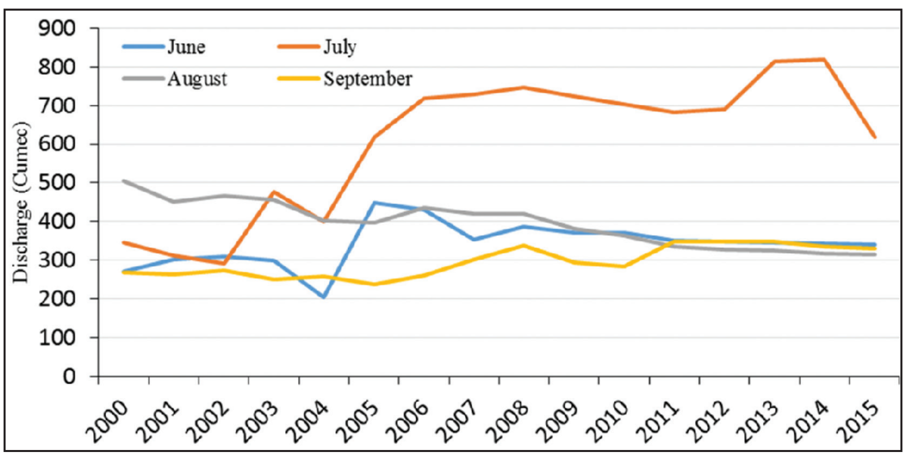

Fig. 6. *Trends in streamflow for monsoon months*

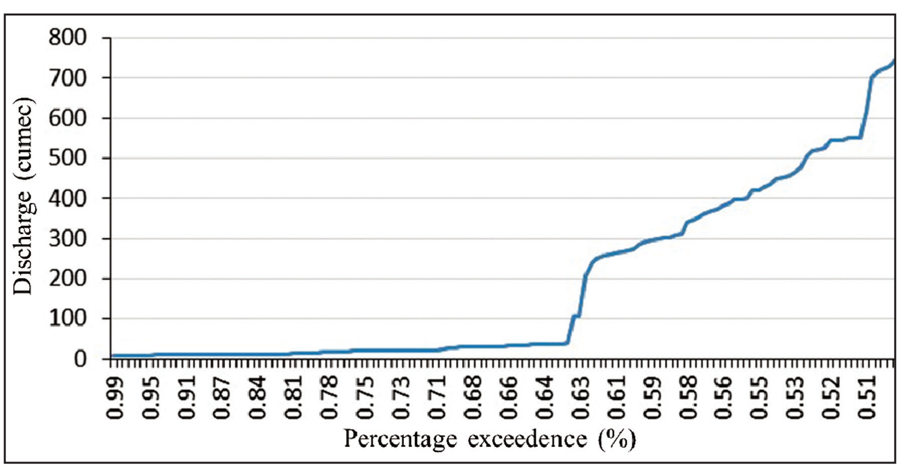

Fig. 7. *Flow duration curve of river discharge*

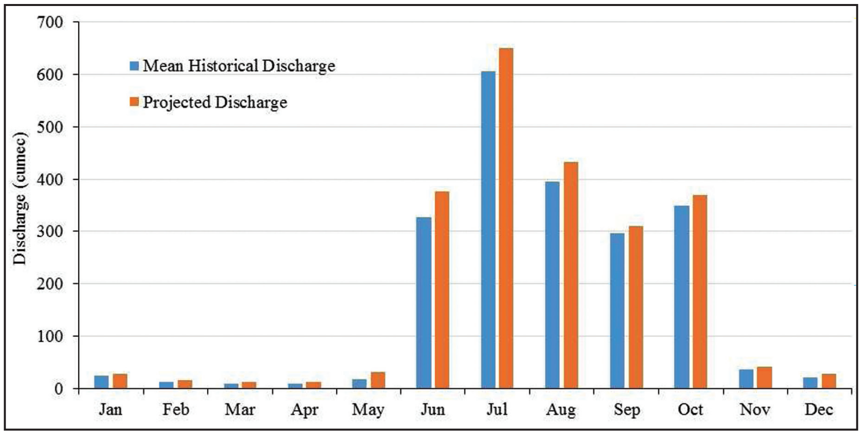

Fig. 8. *Comparison of the historical and projected mean monthly discharge*

and precipitation are the important factors which affect the hydrology of a river basin. Present study analyses the temperature and precipitation trends in the coastal river basin of eastern India. This study finds significantly rising temperature in summer season followed by the increasing precipitation during the monsoon season. Hydrological modeling of the river basin establishes suitable parameter ranges for the physical inputs such as curve number, soil hydraulic conductivity, base-flow factor. Parameterization of the river basin can be helpful to project the hydrological changes in the basin for future climate change scenarios using the different global climate models. In long term, the increasing temperature in the river basin could enhance the evapotranspiration which may increase the crop water requirement during the non-monsoon season. Increasing precipitation in the monsoon season could be harvested for the use in agricultural purposes during the lean season. The present study utilizes only one GCM model and emission scenario *i.e.*, RCP2.6, GCM data was used without downscaling and only bias-correction was performed using the observed datasets, multi-model GCM data analysis and uncertainty analysis for the different emission scenarios can be considered as the future scope of the present study.

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