

# Anthropogenic Influence on Streamflow in the Mahi Bajaj Sagar Basin, India



Mithun Choudhary, Mahesh Kumar Jat, and Mahender Choudhary

**Abstract** Climate change and its impact on associated natural and manufactured systems have stressed water resources. Since the last decade, the flow of most rivers in Rajasthan has been showing a decrease in water. Mahi Sagar reservoir, one of the largest water reservoirs, is also experiencing a decline in river runoff due to climate change impact and human activities. The effect of climate change (CC) on regional hydrology imposes challenges because of the connection between the climate system and the hydrological cycles and the basin's characteristics. Using daily climate data, this research was conducted using hydrological semi-distributed model, and a Soil Water Assessment Tool (SWAT) is verified to a baseline from 1990 to 2005. Subsequently, we reconstructed natural runoff for 2006–2018 without considering the local human impact. We observed short-term variation in streamflow throughout the impact period based on reconstructed streamflow and observed streamflow data. Trend analysis and the SWAT model were taken in the experiment to analyze the relative contribution of CC and human activities on streamflow. The outcome of the study showed that total relative change in the assessment period 2006–2011, 2012–2018, and 2006–2018 is 29%, 48%, and 46%, respectively, and for the same periods, impact by climate change 48%, – 4%, and 26.51%, respectively, and impact by human activities 51%, 104%, and 73.49% on streamflow.

**Keywords** Climate change · SWAT · Streamflow · Trend analysis · Mahi Bajaj Sagar basin

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## 1 Introduction

According to previous scientific research, climate change (CC) is one of the primary factors affecting availability of water and its spatial distribution across the globe. In a developing country such as India, CC and human activities significantly influence regional water resources [1]. Streamflow is an important component of the hydrological cycle in a river catchment. Streamflow unpredictability has an impact on water consumption trends in diverse sectors like agriculture, domestic industry, generation of hydropower, wastewater management units, and navigation [2]. Previously, scientists examined streamflow data to evaluate variability over very long time period and attribute total streamflow fluctuation through time to changes in CC and human activities. Precipitation, evaporation, and soil moisture availability are all affected by climate change [2–4]. Over the last decade, CC studies have been done to assess the impact of CC on water resources at the basin level [5–9] using distributed hydrological, for example, SWAT, VIC, and MIKE-SHE. These models utilize fine resolution data for better accuracy in outcome [10–13]. The distributed hydrological models are the most efficient and reliable modeling tool for (climate change impact assessment) studies [14–16] to understand the hydrological phenomenon at a basin scale because they can easily relate most of the physically observed parameters directly in to the model parameters.

Researchers in the last decade preferred various methodologies to quantify the relative impact of CC and human activities on surface runoff. These methodologies come under certain categories, first category hydrological modeling [17–19], second category climate elasticity [20] and method of decomposition [21], third category hydrological sensitivity method [22], and fourth category experimental approach [23]. The hydrological modeling method is based on the hydrological model because it is technically sound and can physically depict hydrological processes in the watershed. Lumped model as SIMHYD is a version of HYDROLOG model, and the Xinanjiang model [24], etc., lacks in representing underlying surface properties or input parameters of the model in the watershed. Despite the use of lumped models, a semi-distributed model such as SWAT, VIC, GBHM (geomorphological-based model of hydrology) is applied for very long time so that results might be trustable for quantifying the impact of CC and human activities in regional surface runoff. Climate elasticity and decomposition method come under the Budyco framework [25] and also have certain drawbacks as these two methods have functions in the form of equations that impose problems for analyzing variation in runoff in the given scenarios. The hydrological sensitivity method is based on the single factor at a time approach analysis where only one component was changed, while the others remained constant. This method is very time-consuming as it does not provide flexibility in projecting climate change scenario. The most efficient strategy is the experimental approach, which has typically been employed for small catchments; however, it is cost-effective, but it is difficult to apply to a large-sized watershed. Many studies provide access for quantifying the effect of climate change or land use/land cover change on streamflow. These approaches are limited to regional impact assessment.

It is often necessary to determine how much streamflow is influenced by human activity relative to climate change, particularly long-term streamflow observed in the Mahi Bajaj Sagar basin. In the last decade, as the author knows, less attention has been given to the Mahi Bajaj Sagar basin. Therefore, present study investigates the relative impact of CC and human activities on streamflow at the Mahi Bajaj Sagar basin.

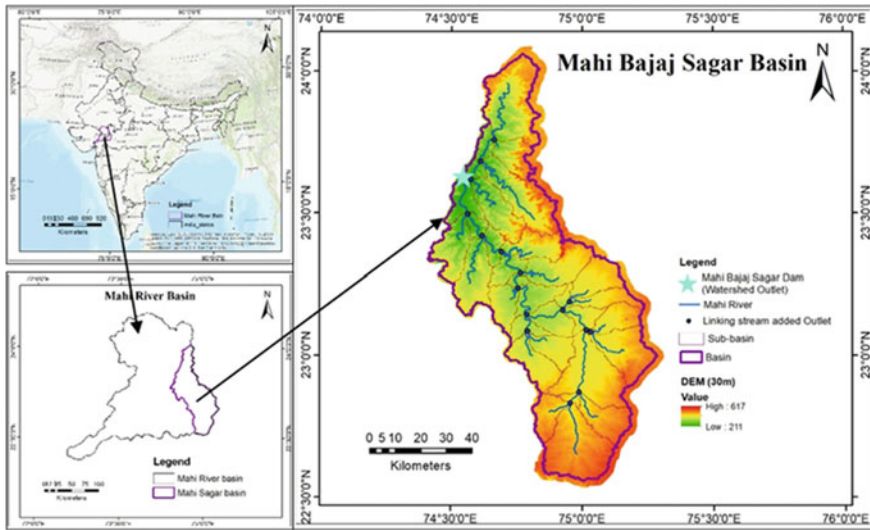
## 2 Study Area and Data Source

### 2.1 Mahi Bajaj Sagar Basin

Mahi Bajaj Sagar basin is a part of Mahi River catchment of India, which is situated in the vicinity of 23°37'37 N and 74°32'39E as shown in Fig. 1. Mahi Bajaj Sagar basin covered 6149 sq.km. Most of the part of the basin is covered with fine loamy-textured soil. The research area receives between 850 and 1000 mm of rain per year. The climate of Mahi Bajaj Sagar basin is semi-arid. It is known for hot summer and general dryness except during the southwest monsoon, which experiences heavy rainfall. The monsoon season is a short period; nearly 85% of the total rainfall comes from this southwest monsoon. Mean monthly air temperature ranges from 12 to 15 °C in winter season and 35–47 °C in summer season. Dominant land use/land cover in the region of Mahi Bajaj Sagar basin is agriculture. Karif and Rabi season are the crop season which required water for irrigation from the Mahi Sagar reservoir. The reservoir's current discharge capacity is 383m<sup>3</sup>/sec and has the potential of maximum discharge 10,887 m<sup>3</sup>/sec from the Mahi Bajaj Sagar basin. Stormwater drainage for the Mahi Bajaj Sagar basin has been disrupted due to the influence of anthropogenic factors such as encroachment of hutments in large numbers, particularly in the surrounding Mahi River in both urban and rural areas.

### 2.2 Data Collection

The long-term available meteorology data from 1975 to 2018 at the daily temporal scale has been used in the present study to arrive at statistical inference. Land use/land cover (LULU) information was extracted from the classification of satellite images for the years 1990 and 2010 from October to November of the Karif season. All of the images used in this study were taken during the post-monsoon season and were cloud-free. The supervised maximum likelihood classification techniques were used to classify LULC images for respective years. Soil information was obtained from food organizations and subset to the study area. DEM data from the United States Geological Survey was obtained and used to delineate the basin at a threshold value of 100 km<sup>2</sup>. Table 1 contains information about the data used in this study.



**Fig. 1** Study area location map of Mahi Bajaj Sagar basin

**Table 1** Data used in the present study

Variable	Period	Temporal resolution	Spatial agency
Precipitation	1975–2018	Daily (25°*25°)	Indian Meteorology Department (IMD)
Temperature (max. and min.)	1975–2018	Daily (05°*05°)	Indian Meteorology Department (IMD)
Observed streamflow	1984–2018	Daily	Rajasthan Government
LULC data	1990, 2010 (Kharif season)	30 m	Landsat Data Satellite Imageries USGS ( <a href="http://earthexplorer.usgs.gov/">http://earthexplorer.usgs.gov/</a> )
Soil data	1971–1981	1 km	Harmonized World Soil Database v1.2, FAO UNESCO soil map of the world ( <a href="https://www.fao.org/soils-portal/">https://www.fao.org/soils-portal/</a> )
DEM	—	30 m	ASTER Data USGS

### 3 Method

#### 3.1 Quantifying Impacts on Streamflow

Individual impacts of CC and human activities (anthropogenic) in terms of LULC change on basin hydrology are challenging to investigate. This present study estimates the relative impact of CC and human activity on runoff and method adopted from [19]. In the present study, meteorological data for 35 years (1984–2018) has been used as a baseline case to determine the effect of CC on runoff regime of the study area. A semi-distributed hydrological model (SWAT) was used. SWAT simulates watershed hydrological response as a function of meteorological and LULC characteristics over a period in Mahi Bajaj Sagar basin. SWAT model was conceptualized for the study area, and calibrated and validated periods are provided in Table 2. Calibrated SWAT model was applied to simulate rainfall-runoff for the study area considering constant LULC conditions from 1990 to 2005. The constant change in hydrological response of watershed with constant LULC reflects the influence of the effect of CC alone that is the change produced by precipitation and temperature. The second simulation hydrology of the basin was simulated from 2006 to 2018 using a calibrated model with the same setting for generating natural streamflow without considering local human activities, such as no LULC change. The difference between streamflow during the impact period and streamflow during the baseline period is made up of two parts. One part is the possible changes due to human activities as  $\Delta R_h$  and the second part from climate change as  $\Delta R_c$ , observed streamflow denoted as  $R_i$ , and the streamflow corresponding to the baseline period is  $R_b$ . As a result, the major difference between observed streamflow for the period of assessment and the period of baseline reflects the streamflow response as shown in Eqs. (1–2) sum of  $\Delta R_h$  and  $\Delta R_c$

$$\Delta R_h + \Delta R_c = R_i - R_b \tag{1}$$

$$\Delta R_h = R_i - R_m \tag{2}$$

$$\Delta R_c = R_m - R_b \tag{3}$$

**Table 2** Calibration and validation monthly simulation at Mahi Bajaj Sagar basin

Variable	Calibration (1990–2005)	Validation (2006–2010)
$R^2$	0.74	0.70
NSE	0.73	0.72
PBIAS	- 0.20	- 12.20

\* NSE Nash–Sutcliffe;

\* PBIAS Percentage BIAS

where  $\Delta R_h$  ( $\text{m}^3/\text{s}$ ) is change in runoff due to human-induced activities,  $\Delta R_c$  ( $\text{m}^3/\text{s}$ ) is change in runoff due to effect of CC,  $R_b$  is the observed runoff for yearly basis in the period of assessment in  $\text{m}^3/\text{s}$ , and  $R_m$  is the generated or reconstructed streamflow monthly basis (latter converted to yearly basis) for the period of assessment by the use state of art hydrological model.

$$PR = \frac{R_i}{R_b} - 1 \times 100\% \quad (4)$$

where the percentage of change in the observed annual runoff in the baseline period is denoted by PR (relative change).

The percentage change from human activities and CC is estimated in respective time frames by Eqs. (5) and Eq. (6) and denoted by (PH, PC)

$$PH = \frac{\Delta R_c}{\Delta R_h + \Delta R_c} \times 100\% \quad (5)$$

$$PH = \frac{\Delta R_c}{\Delta R_h + \Delta R_c} \times 100\% \quad (6)$$

### 3.2 SWAT Model Setup

The USDA Agriculture Research Service's Soil Water Assessment Tool (SWAT Model) [26] is the outcome of nearly 40 years of modeling work [27]. SWAT model is a basin-scale model classified as semi-distributed. It follows the continuous-time model and operates in daily time steps. The SWAT model is intended to simulate various hydrological components of the water cycle as well as various water, agriculture, and sediment yield management processes. SWAT is physically based and can simulate for long periods of time. It takes less time to simulate the process. The SWAT model required climate data input as well as observed data for model validation.

### 3.3 Mann-Kendall's Test

The M-K method is used to analyze climate and environmental time series data. It was proposed by [28] and is frequently used with time series [29] of climate data. This test has two benefits. First, it is a nonparametric measure that does not require the data to be distributed on a regular basis. Second, because time series are inhomogeneous, it is impervious to abrupt breaks. The null hypothesis  $H_0$  states that no trend exists (data is independent and randomly ordered) [30]. This test was performed against the

alternative hypothesis H1, which supposes that the data exhibits the trend depicted in Eq. 4.

$$S = \sum_{k=1}^{n-1} \sum_{k+1}^n \text{sgn}(x_j - x_k) \tag{7}$$

The trend test is applied to time series  $x_k$ , which is ranked  $k = 1, 2, 3 \dots n - 1$ , which is ranked for  $j = i, i + 1, i + 2, i + 3 \dots$  each data point  $x_j$  is used as a reference point, as shown in Eq. 5 [30].

$$\begin{aligned} \text{sgn}(x_j - x_k) &= 1 \text{ if } x_j - x_k > 0 \\ &= 0 \text{ if } x_j - x_k = 0 \\ &= -1 \text{ if } x_j - x_k < 0 \end{aligned} \tag{8}$$

### 3.4 Sen’s Slope Test

The magnitude of the trend can be calculated using Sen’s slope estimator in time series [30, 31]. To measure the real slope of an existing trend, such as the quantity of change per year, Sen’s nonparametric approach [30] was applied, and the test was conducted using the MAKESENS micro excel [32].

## 4 Results and Discussions

### 4.1 Precipitation and Temperature Trend Analysis at the Mahi Bajaj Sagar Basin

Figure 2 depicts the precipitation trend in the Mahi Bajaj Sagar basin. In the selected period, the observed precipitation shows a decreasing trend, and observed air temperature shows an increasing trend. Precipitation and temperature had regression slopes of  $- 1.52$  and  $0.011$ , respectively. The observed precipitation reached a maximum of  $1564.22$  mm in 1994 and a minimum of  $442.16$  mm in 2000. The decadal variability in precipitation at the Mahi Bajaj Sagar basin depicted was uneven distribution. The temperature varies greatly during the summer season. As a result, there is variation from north to south in the Mahi Bajaj Sagar basin. The maximum air temperature was  $44.84$  °C shown in the year 1991. In the winter season, less variation forms south to north but high variation in the east to the west section of Mahi Bajaj Sagar basin during the period 1984–2018. The lowest air temperature is observed in the year 1990 which is  $4.29$  °C. The results of the applied test (Mann-Kendall) showed the

decreasing trend for annual precipitation during the period 1984–2018 at the Mahi Bajaj Sagar basin. However, the predicted trend is insignificant (Fig. 2). Similarly, for air temperature, the trend increases for both maximum and minimum air temperatures (Figs. 3 and 4). Furthermore, for this period, step-change precipitation and temperature were not taken into account. The Mahi Bajaj Sagar basin’s climate has warmed over the last 35 years (Fig. 4). Year 1990 was the coldest year, followed by 1977. Temperature increased from 1984 to 2018, according to the Mann-Kendall test results (Fig. 3). During the years 1984–2018, there was a statistically significant trend. The overall analysis of precipitation and temperature shows climate change in the region of Mahi Bajaj Sagar basin.

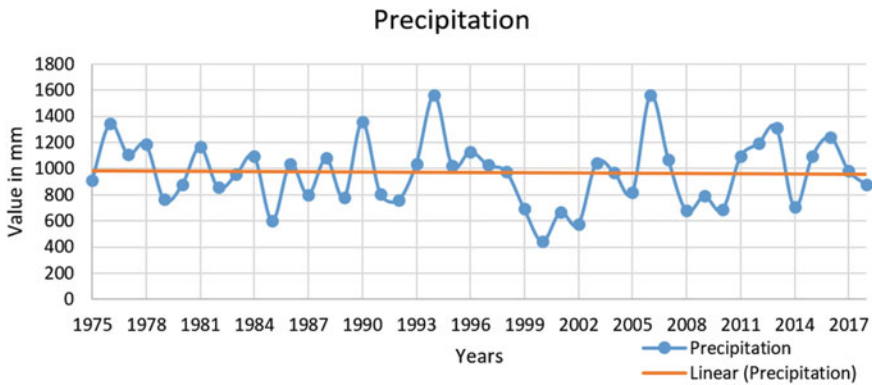


Fig. 2 Trend in observed annual precipitation using Mann-Kendall test percentage error

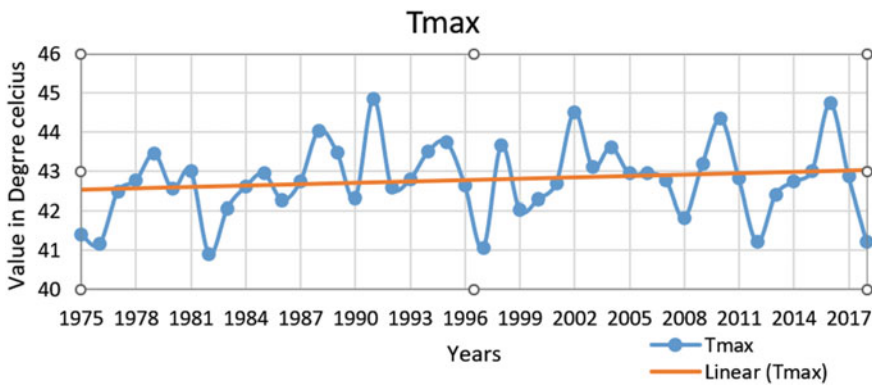


Fig. 3 Annual maximum temperature using Mann-Kendall trend



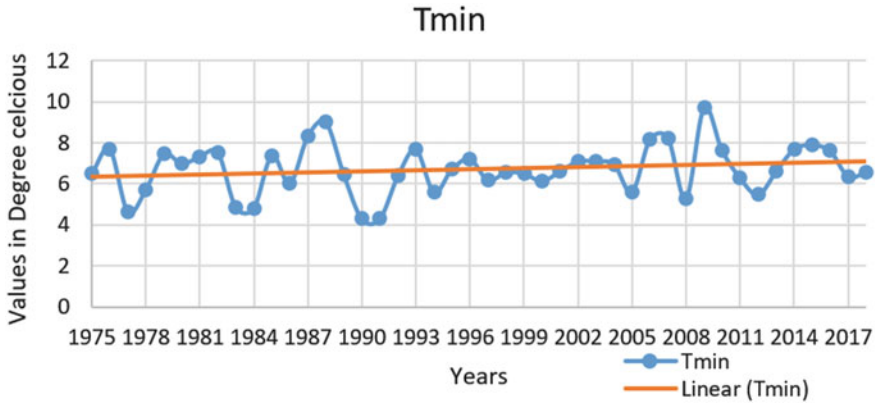


Fig. 4 Annual minimum temperature using Mann-Kendall trend

### 4.2 Streamflow Trend Analysis at the Mahi Bajaj Sagar Basin

Figure 5 depicts the observed annual streamflow at the Mahi Bajaj Sagar basin outlet from 1984 to 2018. The findings of the Mann-Kendall test revealed a statistically significant decrease in yearly streamflow for the Mahi Bajaj Sagar basin. The regression slope was  $-0.54$ , detected by Sen's slope estimator. Significant step-change point is not observed. But outliers were present in the streamflow in the years 1984, 2011, and 2017. The minimum flow in the year 2000 was  $10 \text{ m}^3/\text{sec}$ , and the maximum flow in the year 2011 was  $269.89 \text{ m}^3/\text{sec}$ .

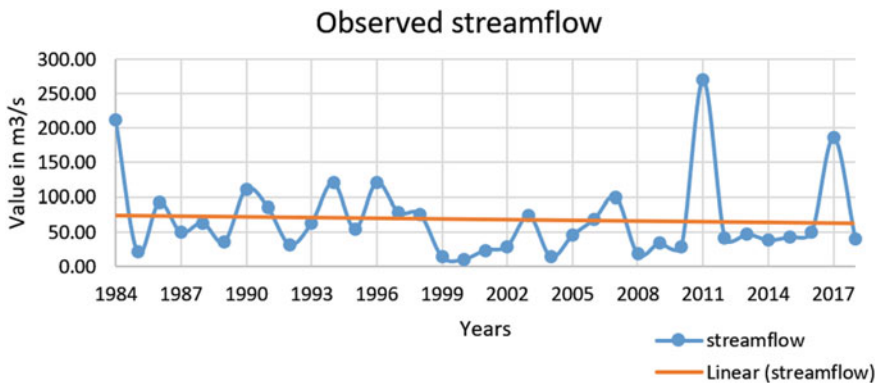


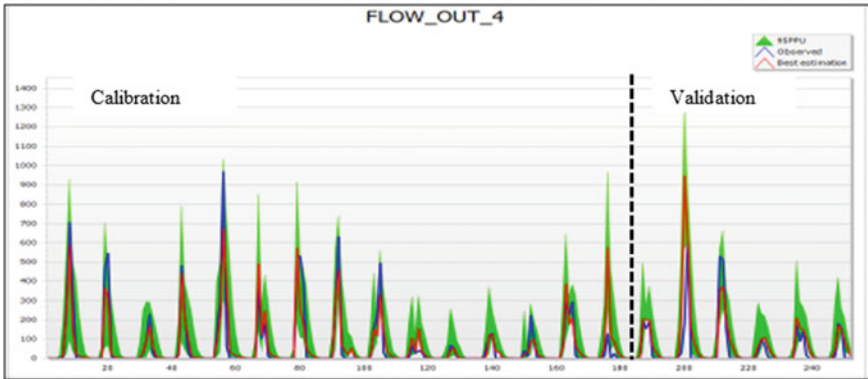
Fig. 5 Annual observed streamflow at the outlet of Mahi Bajaj Sagar basin

### 4.3 Performance of SWAT Model

The calibration process was applied to the SWAT model using the SWAT-Cup [33] uncertainty program. The sensitive parameters for runoff were determined during the calibration of the SWAT model [2]. Table 3 lists their statistical data and rankings. The most responsive surface runoff parameter was 11 parameters, i.e., compensation factor for soil evaporation (ESCO), followed by the saturated hydraulic conductivity of the soil (Sol\_K), initial SCS-CN II value in runoff process (CN2), alpha factor for base flow in groundwater simulation (Alpha\_BF), groundwater delay which has units in days (GW\_Delay), water capacity available in the soil layer (SOL\_AWC), shallow aquifer threshold depth required for groundwater (GWQMN), plant uptake compensation factors in evaporation process (EPCO), hydraulic conductivity in the main channel alluvium (CH\_K2), Manning's "n" value in channel process (CH\_N2), and average slope steepness in the geomorphological process (HRU\_SLP). These parameters were found to be best for the simulated model after sensitivity analysis throughout the calibration process. In this study, ESCO.hru, Sol\_K.sol, and CN2.mgt are the most sensitive parameters, followed by other parameters as shown in Table 3. In SWAT-CUP, sensitivity estimation t-stat and p-value factor are taken [34]. Most sensitive parameters, according to their rank, directly reflect an understanding of the basin's hydrology. All the parameters have rank depending on the sensitivity statistics such as maximum and minimum values and fitted value of the parameters. Calibration statistics illustrated in Table 2 for the Mahi Bajaj Sagar basin were verified as per the criteria followed by researchers [35–37]. To use the hydrological model to simulate streamflow for the baseline period and impact period, SWAT model calibrates for baseline period and natural streamflow which is generated for impact period. Figure 6 depicts graph for model-simulated streamflow compared to observed streamflow for the Mahi Bajaj Sagar basin outlet.

**Table 3** Parameters selected for the calibration of the SWAT model

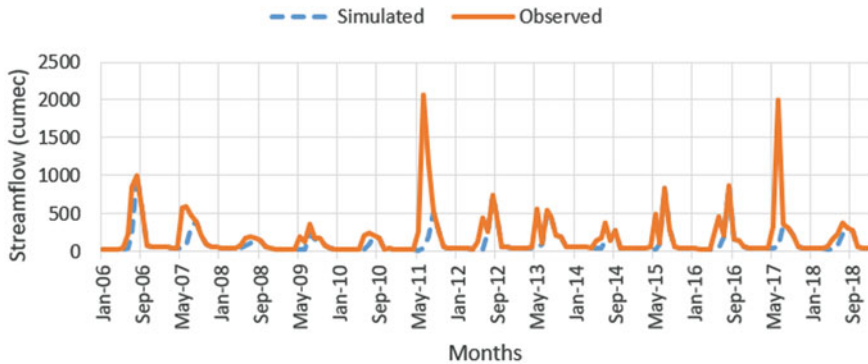
Parameters	Parameter initial max. range	Parameter initial min. range	Fitted value	Rank
V_ESCO.hru	0.34	1.02	0.39	1
R_SOL_K.sol	0.00	1077.36	3.05	2
R_CN2.mgt	− 0.25	0.04	− 0.01	3
V_ALPHA_BF.gw	0.39	1.18	0.96	4
V_GW_DELAY	0.00	296.11	84.39	5
R_SOL_AWC.sol	0.00	0.518	0.09	6
A_GWQMN.gw	2032.10	6117.89	3833.93	7
R_EPCO.hru	0.09	0.07	0.82	8
V_CH_K2	− 0.66.93	311.78	− 41.56	9
V_CH_N2	0.0	0.29	0.14	10
R_HRU_SLP.hru	0.41	1.24	0.49	11



**Fig. 6** Plot for observed and simulated runoff at Mahi Bajaj Sagar basin

### 4.4 Streamflow Reconstruction for Impact Period

After the SWAT model calibration process, use the same hydrometeorological condition for the baseline. Calibrated SWAT model was used to reconstruct the natural streamflow data for the impact period from 2006 to 2018 with no local human activity. (No changes in land use/land cover in the basin). Figure 7 shows reconstructed streamflow from calibrated SWAT model for Mahi Sagar basin.



**Fig. 7** Monthly time series of streamflow and simulated streamflow for period 2006–2018 at the outlet of Mahi Bajaj Sagar basin

#### 4.5 Quantification of Impacts on Streamflow at Mahi Bajaj Sagar Basin

In this study, the observed runoff and reconstructed streamflow by hydrological model and the impact of CC and human activities on runoff were calculated using Eqs. (1)–(6) for impact period and summarized in Table 4. The observed and reconstructed average annual streamflow at the Mahi Bajaj Sagar basin accounted 1474.92 m<sup>3</sup>/sec and 935.29 m<sup>3</sup>/sec in the baseline period. Three observations are shown in Table 4. First, the average yearly streamflow for 2006–2018 was smaller than the baseline case, which implies that the observed runoff at the Mahi Bajaj Sagar basin falls under the selected period. The absolute and relative combined impacts of CC and human activities on streamflow accounted 680.35 cumecs and 46.13%, respectively. The most significant impact observed is 709.25 cumecs and 48.09%, respectively, appearing in the 2012 impact period (2012–2018). Second, the difference between the natural streamflow (reconstructed streamflow) and the streamflow of the baseline case shows the deficient streamflow because of CC. Figure 8 depicts human activities responsible for streamflow changes, especially downstream in the different periods. The changes in streamflow because of climate change (PC) were 48.64% and –4.70% in the years 2006 to 2011 and 2012 to 2018, respectively. For the same years, changes caused by human activities (PH) were 51.36% and 104%, respectively, on streamflow. Third, in the impact period 2006 to 2018, human activities and CC contributed for 73.49 and 26.51% of the overall decline in the runoff. Human activities are the primary cause of the recently identified decreased runoff in the Mahi River in the Mahi Bajaj Sagar basin.

**Table 4** Impact of CC and human activity on runoff at Mahi Bajaj Sagar basin

Period	Observed streamflow (m <sup>3</sup> /sec)	Reconstructed streamflow (m <sup>3</sup> /sec)	Total change [PR (%)]	Impact of climate change [PC (%)]	Impact of human activities [PH (%)]
Baseline Period (1990–2005)	1474.92	935.29			
Impact Period (2006–2011)	1039.41	1263.09	29.58	48.64	51.36
Impact Period (2012–2018)	765.67	1508.16	<b>48.09</b>	– 4.69	104.69
Impact Period (2006–2018)	794.57	1294.58	<b>46.13</b>	<b>26.51</b>	<b>73.50</b>

*PR* Percentage of relative change

*PC* Percentage of climate change

*PH* Percentage of human activities

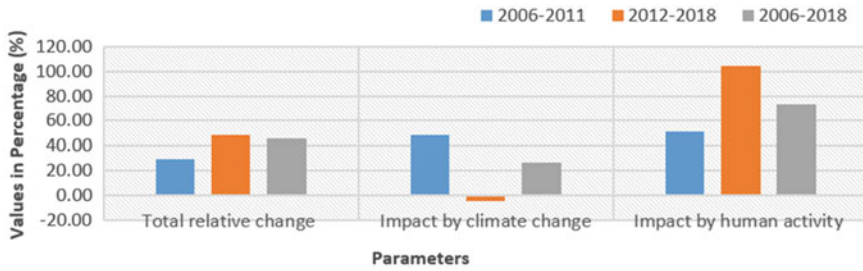


Fig. 8 CC and human activities at Mahi Bajaj Sagar basin

### 4.6 Discussion and Conclusion

Previous studies are conducted for quantification of climate influence in the basin. Basin characteristics and local activities in terms of LULC affect the streamflow. Streamflow is the resultant of various catchment hydrological processes and is impacted by so many factors. Changes in streamflow can be caused by any factor, including climate and LULC. However, quantifying the individual impact is quite difficult as major changes are linked with climate and human activities. The result from this study shows the percentage of changes from both phenomena in the hydrological system. From this study’s conclusion, human activities impact streamflow is significantly higher than climate change impact. Similar results found in studies done over last 10 years. Thier studies reported that climate change might be factor for the variation in runoff [17, 38, 39]. On the other side some researchers [15, 20, 40, 41] found human activities are primary factors for variation in runoff. In addition to this, urban expansion [42] is also responsible for variation of surface runoff in diverse catchment like Mahi Bajaj Sagar basin. Large-scale human activities, including excessive irrigation and soil conservation practices and change in land use/land cover, are the direct factors for reducing the streamflow in the Mahi Bajaj Sagar basin.

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## References

1. Mondal A, Narasimhan B, Sekhar M, Mujumdar PP (2016) Hydrologic modelling. *Proc Indian Natl Sci Acad* 82:817–832. <https://doi.org/10.16943/ptinsa/2016/48487>
2. Dey P, Mishra A (2017) Separating the impacts of climate change and human activities on streamflow: a review of methodologies and critical assumptions. *J Hydrol* 548:278–290. <https://doi.org/10.1016/j.jhydrol.2017.03.014>
3. Gleick PH (1989) Climate change. *Hydrology* 329–344
4. Dooge JCI (1992) Sensitivity of runoff to climate change: a Hortonian approach. *Bull Am Meteorol Soc* 73:2013–2024
5. Chawla I, Mujumdar PP (2015) Isolating the impacts of land use and climate change on streamflow. *Hydrol Earth Syst Sci* 19:3633–3651. <https://doi.org/10.5194/hess-19-3633-2015>
6. Deshpande NR KB (2014) Assessing hydrological response to changing climate in the Krishna Basin of India. *J Earth Sci Clim Change* 5. <https://doi.org/10.4172/2157-7617.1000211>
7. Wijesekara G (2013) An integrated modeling system to simulate the impact of land-use changes on hydrological processes in the Elbow River watershed in Southern Alberta, vol 167. <https://doi.org/10.11575/PRISM/24908>
8. Omer A, Elagib NA, Zhuguo M et al (2020) Water scarcity in the Yellow River Basin under future climate change and human activities. *Sci Total Environ* 749:141446. <https://doi.org/10.1016/j.scitotenv.2020.141446>
9. Oeurng C, Cochrane TA, Chung S et al (2019) Assessing climate change impacts on river flows in the Tonle Sap Lake Basin, Cambodia. *Water (Switz)* 11. <https://doi.org/10.3390/w11030618>
10. Devatha CP, Deshpande V, Renukaprasad MS (2015) Estimation of soil loss using USLE model for Kulhan Watershed, Chattisgarh—a case study. *Aquat Procedia* 4:1429–1436. <https://doi.org/10.1016/j.aqpro.2015.02.185>
11. Singh G, Kumar E (2017) Input data scale impacts on modeling output results: a review. *J Spat Hydrol* 13
12. Sahana V, Timbadiya PV (2020) Spatiotemporal variation of water availability under changing climate: case study of the Upper Girna Basin, India. *J Hydrol Eng* 25:05020004. [https://doi.org/10.1061/\(asce\)he.1943-5584.0001890](https://doi.org/10.1061/(asce)he.1943-5584.0001890)
13. Shivhare N, Dikshit PKS, Dwivedi SB (2018) A comparison of SWAT Model calibration techniques for hydrological modeling in the Ganga River watershed. *Engineering* 4:643–652. <https://doi.org/10.1016/j.eng.2018.08.012>
14. Mango LM, Melesse AM, McClain ME et al (2011) Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modeling study to support better resource management. *Hydrol Earth Syst Sci* 15:2245–2258. <https://doi.org/10.5194/hess-15-2245-2011>
15. Wang GQ, Zhang JY, Pagano TC et al (2013) Identifying contributions of climate change and human activity to changes in runoff using epoch detection and hydrologic simulation. *J Hydrol Eng* 18:1385–1392. [https://doi.org/10.1061/\(asce\)he.1943-5584.0000559](https://doi.org/10.1061/(asce)he.1943-5584.0000559)
16. Sinha RK, Eldho TI, Subimal G (2020) Assessing the impacts of land use/land cover and climate change on surface runoff of a humid tropical river basin in Western Ghats, India. *Int J River Basin Manag* 1–38. <https://doi.org/10.1080/15715124.2020.1809434>
17. Ma Z, Kang S, Zhang L et al (2008) Analysis of impacts of climate variability and human activity on streamflow for a river basin in arid region of northwest China. *J Hydrol* 352:239–249. <https://doi.org/10.1016/j.jhydrol.2007.12.022>
18. Li Z, Liu W, Zhang XC, Zheng FL (2009) Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. *J Hydrol* 377:35–42. <https://doi.org/10.1016/j.jhydrol.2009.08.007>
19. Chang J, Wang Y, Istanbuluoglu E et al (2015) Impact of climate change and human activities on runoff in the Weihe River Basin, China. *Quat Int* 380–381:169–179. <https://doi.org/10.1016/j.quaint.2014.03.048>

20. Zheng H, Zhang L, Zhu R et al (2009) Responses of streamflow to climate and land surface change in the headwaters of the Yellow River Basin. *Water Resour Res* 45:1–9. <https://doi.org/10.1029/2007WR006665>
21. Wang D, Cai X (2010) Comparative study of climate and human impacts on seasonal baseflow in urban and agricultural watersheds. *Geophys Res Lett* 37:1–6. <https://doi.org/10.1029/2009GL041879>
22. Zuo D, Xu Z, Wu W et al (2014) Identification of streamflow response to climate change and human activities in the Wei River Basin, China. *Water Resour Manag* 28:833–851. <https://doi.org/10.1007/s11269-014-0519-0>
23. Brown AE, Zhang L, McMahon TA et al (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *J Hydrol* 310:28–61. <https://doi.org/10.1016/j.jhydrol.2004.12.010>
24. Xu CY (1999) Climate change and hydrologic models: a review of existing gaps and recent research developments. *Water Resour Manag* 13:369–382. <https://doi.org/10.1023/A:1008190900459>
25. Lee C-H, Yeh H-F (2019) Impact of climate change and human activities on streamflow variations based on the Budyko Framework. *Water* 11
26. Kumar N (2014) Impacts of climate change and land-use change on the water resources of the Upper Kharun Catchment, Chhattisgarh, India, pp 16–17
27. Williams JR, Arnold JG, Kiniry JR et al (2008) History of model development at Temple, Texas. *Hydrol Sci J* 53:948–960. <https://doi.org/10.1623/hysj.53.5.948>
28. Mann HB (1945) Nonparametric tests against trend. *The Econometric Society Stable*. <https://www.jstor.org/stable/1907187>. References Linked references are available on JSTOR for this article: You may need to log in to JSTOR. *Econometrica* 13:245–259
29. Prajapat DK, Lodha J, Choudhary M (2020) A spatiotemporal analysis of Indian warming target using CORDEX-SA experiment data. *Theor Appl Climatol* 139:447–459. <https://doi.org/10.1007/s00704-019-02978-7>
30. Panda A, Sahu N (2019) Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. *Atmos Sci Lett* 20:1–10. <https://doi.org/10.1002/asl.932>
31. Sen PK (1968) Estimates of the regression coefficient based on Kendall's Tau. *J Am Stat Assoc* 63:1379–1389. <https://doi.org/10.1080/01621459.1968.10480934>
32. Salmi T (2002) Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates-the Excel template application MAKESENS. *Ilmatieteen laitos*
33. Abbaspour KC (2012) *Swat-cup 2012*. SWAT Calibration uncertain program—a user man, vol 106
34. Abbaspour KC, Vaghefi SA, Srinivasan R (2017) A guideline for successful calibration and uncertainty analysis for soil and water assessment: a review of papers from the 2016 international SWAT conference. *Water (Switz)* 10. <https://doi.org/10.3390/w10010006>
35. Narsimlu B, Gosain AK, Chahar BR et al (2015) SWAT model calibration and uncertainty analysis for streamflow prediction in the Kunwari River Basin, India, using sequential uncertainty fitting. *Environ Process* 2:79–95. <https://doi.org/10.1007/s40710-015-0064-8>
36. Gassman PW, Arnold JG, White M et al (2010) The worldwide use of the SWAT model: networking impacts, simulation trends, and future developments. In: *Proceedings of watershed technological conference, February 21–24 Costa Rica American Society of Agricultural Biological Engineering Earth University*
37. Tankpa V, Wang L, Awotwi A et al (2021) Modeling the effects of historical and future land use/land cover change dynamics on the hydrological response of Ashi watershed, northeastern China. *Environ Dev Sustain* 23:7883–7912. <https://doi.org/10.1007/s10668-020-00952-2>
38. Kazemi H, Sarukkalghe R, Badrzadeh H (2019) Evaluation of streamflow changes due to climate variation and human activities using the Budyko approach. *Environ Earth Sci* 78:1–17. <https://doi.org/10.1007/s12665-019-8735-9>

39. Wu J, Miao C, Zhang X et al (2017) Detecting the quantitative hydrological response to changes in climate and human activities. *Sci Total Environ* 586:328–337. <https://doi.org/10.1016/j.scitotenv.2017.02.010>
40. Jiang S, Ren L, Yong B et al (2011) Quantifying the effects of climate variability and human activities on runoff from the Laohahe basin in northern China using three different methods. *Hydrol Process* 25:2492–2505. <https://doi.org/10.1002/hyp.8002>
41. Dong W, Cui B, Liu Z, Zhang K (2014) Relative effects of human activities and climate change on the river runoff in an arid basin in northwest China. *Hydrol Process* 28:4854–4864. <https://doi.org/10.1002/hyp.9982>
42. Jat MK, Choudhary M, Saxena A (2017) Urban growth assessment and prediction using RS, GIS and SLEUTH model for a heterogeneous urban fringe. *Egypt J Remote Sens Sp Sci* 20:223–241