Sensitivity Analysis of the Physiographic Parameters of the Teesta River Basin by Hydrological Modelling

ABSTRACT

Estimating the discharge from a rainfall event is a challenging task because of a number of affecting elements. A multitude of physiographic factors are essential for both channel and surface flow. In a developing nation like Bangladesh, discharge measurement is critical for forecasting floods, managing land, measuring sediment, nutrientsand promoting sustainable development. It is possible to measure the discharge and physiographic parameter using a hydrological model. Using a semi-distributed model Soil and water Assessment Tool (SWAT), the discharge of the Teesta River Basin, one of the most significant basins of Bangladesh, is simulated for the years 2003 to 2020. Sequential Uncertainty Fitting version 2 (SUFI-2) technique within SWAT-CUP (SWAT Calibration Uncertainty Program) is used to accomplish model calibration and validation for daily time periods utilizing physiographic parameters. The simulation period of this study spans from 2003 to 2020, and the meteorological data utilized includes temperature, wind speed, relative humidity and rainfall. With NSE = 0.89 and R^2 = 0.90, our calibration results for the time period 2003–2011 demonstrated a strong correlation between observed and simulated discharge. Reasonable values are obtained for the NSE andR^2, which are 0.65 and 0.70 for the validation period 2012-2020. Sensitivity analysis is an integral part of model development and involves analytical examination of input parameters to aid in model validation and provide guidance for future researchand sustainable development. Sensitivities of physiographicparameters have been analyzed using SUFI-2 algorithm in SWAT-CUP. It is done by global and one-at-a-time sensitivity procedures. For the Teesta river basin parameters coefficient curve number CN2.mgt, saturated hydraulic conductivity of the soil lair SOL_K ().sol and soil bulk density SOL_BD().sol show most sensitivity forboth of global and one-at-a-time sensitivity procedures.The findings contribute to predict the discharge in period of no observe dataas well asto enhance the understanding and informing decision-making processes for sustainable water resource management.

Keywords: SWAT, SWAT-CUP, SUFI-2, Teesta River, Calibration and Validation, Sensitivity Analysis

1. INTRODUCTION

Bangladesh is a riverine country that is extremely vulnerable to adverse weather.It is recognized for having one of the most vulnerable climates to the adverse effects of climate change. Its tropical monsoon climate is marked by high temperatures, humidity and substantial seasonal precipitation. The region in South Asia Bangladesh occupies an area of 1,47,610 square kilometers and is situated between 20°34' and 26°38' north latitude and 88°01' to 92°42'east longitude.Northern area of Bangladeshis renowned for having an abundance of little rivers and streams. The Teesta is one of the main river systems in northern region of Bangladesh. The physiographic features, flows, and sensitivity of the Teesta River make it a worthwhile study.Near the Chinese border, in the Indian state of Sikkim, the Teesta River rises from the eastern Himalayas[1]. Before entering Bangladesh, it passes through West Bengal and Sikkim in India.The Teesta River passes through Lalmonirhat, Rangpur, Nilphamari, Gaibandha, and Kurigram as it makes its way through northern regions ofBangladesh. Eventually, it joins the Brahmaputra River close to Chilmari.The river is essential to the livelihoods of millions of people in the northern region, enabling them to continue farming and leading traditional lives [25-27].The physiographic elements of the basin, which include geological formations, hydrological processes, land cover patterns, climatic fluctuations, and topographical features, profoundly influence its hydrological regimes, water quality, and ecological functions. To fully understand their impact on basin dynamics and vulnerabilities, a thorough sensitivity study of these parameters is necessary. Through an exploration of parameter sensitivity, this study aims to clarify the fundamental forces behind change, pinpoint critical vulnerabilities, and facilitate well-informed choices for conservation and sustainable management in the Teesta River Basin.Previous studies in the Teesta River Basin have mostly used hydrological modeling and empirical observations to better understand hydrological dynamics [2], flood predictions [3], and water resource management techniques[4]. The majority of the work that has been conducted in the Teesta River Basin focused on how climate change is affecting hydrological processes[5], frequently by looking at scenario-based assessments by Hatui et al[6]and future climate forecast by Rahmanet al [7]. Moreover, impact of flood on groundwater hydrochemistry, contamination of heavy metals in the sediments of tropical ecosystem and isotopic study on the effect of reservoirs and drought on water cycle dynamics are investigated [8-10].The aforementioned studies emphasized the importance of including sensitivity analysis and uncertainty quantification into hydrological models in order to improve prediction reliability and effectively guide adaptive actions.Nonetheless, there is no research on the sensitivity analysis of physiographic parameters in this basin.Using several software programs, the study aims to estimate the discharge of the Teesta River basin in addition to soil type, land use, and other hydrological and climatic data that corresponds with it. The simulated and observed data is then be compared. Subsequently, we examined sensitivity of physiographic factors that are susceptible to discharge and impact river flow, which can be employed to gauge discharge in the absence of observational data.

2. STUDY AREA AND METHODS

2.1 Study Area

The Teesta River Basin, nestled within the Eastern Himalayas, stands as a quintessential example of a watershed shaped by diverse physiographic features and intricate hydrological processes. Spanning across regions of India, Bhutan, and Bangladesh, this basin encompasses an area of approximately 12,000 square kilometers, serving as a vital lifeline for millions of inhabitants who rely on its water resources for sustenance, livelihoods, and socio-economic development[3].Our study area is the Teesta River in the northern portion of Bangladesh, close to Kaunia station in the Rangpur District. Regarding water resources, agriculture, the economy, biodiversity, renewable energy, transboundary relations, and climate change adaptation, Bangladesh greatly benefits from the Teesta River. It is essential to the lives of millions of individuals as well as the nation's general progress.The specific area of Teesta river basin for study is shown in Figure1.

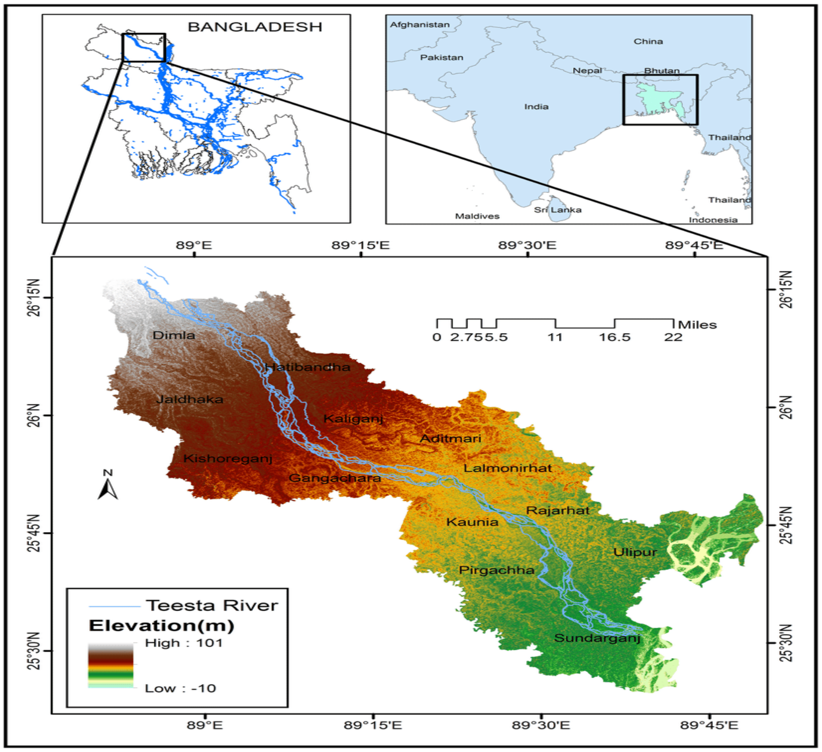

Fig. 1. Teesta River Basin[11]

2.2Methods

Outstanding characteristics make the SWAT model an excellent choice for agricultural watershed applications, and SWAT applications have been successfully calibrated and validated in multiple locations across the US and other continents[12]. In order to predict how land management methods would affect the yields of water, sediment, and agricultural chemicals in large, intricate watersheds, SWAT was developedby UnitedStates Department of Agriculture (USDA) [13-16]. Rather of use regression models to connect data, SWAT is a physically grounded method. Determining the relationship between variables that act as inputs and outputs is the goal of the SWAT technique. A variety of physical processes related to watersheds can be simulated thanks to SWAT. It is not the goal of SWAT, a constant-time model, to replicate intricate, one-time flood routing.Simulation of the hydrologic cycle is based on the water balance equation in SWAT is

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{sep} - Q_{gw})$$

where $t$is the time in days, SW_t and SW_0 are the final and initial soil water content on day i (mm H_2O) respectively, $Q_{surf}$is the amount of surface runoff on the day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), $W_{sep}$is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount ofreturn flow on day i (mm H_2O).

The methodology encompasses data collection and preprocessing, hydrological modeling approaches, sensitivity analysis techniques, and model calibration and validation procedures. A version of Arc GIS 10.3 with the extension program Soil and Water Assessment tool (SWAT) was used to generate a hydrological model[16]. A large number of unique and time series datasets are needed to construct the water balance in a SWAT model. Hydrological models are made with a variety of data types, such as:

- DEM (Digital Elevation Model)
- Soil data
- Landcover/ Land-use data
- Weather data (precipitation, temperature, Humidity, wind speed)
- River outflow i.e river discharge

These data, which were compiled from a variety of sources, are crucial to the creation of the SWAT model.The Watch Forcing Data methodology applied to ERA-Interim reanalysis data (WFDEI), Bangladesh Meteorological Department (BMD), the Bangladesh Water Development Board (BWDB), the United States Geological Survey (USGS), the Food and Agricultural Organization (FAO) and other secondary sources were among the sources from which the data were compiled. The following table exposes the required data with data sources.

Table 1. Data used to construct the SWAT model and sources of the data

Variable Name	**Data Source**
Digital elevation model	SRTM
Land use map	GLOBCOVER
Soil map	FAO-UNESCO
Discharge Data	BWDB
Stream Network Data	USGS Hydro-SHEDS
Climate Data	WFDEI

2.2.1 Digital Elevation Model (DEM)

This study use 90m resolution Digital Elevation Model (DEM) from the ShuttleRadar Topographic Mission (SRTM). The open source ishttps://srtm.csi.cgiar.org/srtmdata/ where it is being downloaded. Topography, which provides theexact spatial resolution of every point's elevation in a given area, was defined usinga digital elevation model (DEM).A DEM was processed as input, and utilizing the DEM and river form, the flowdirection, flow accumulation, stream network generation, and watershed and sub-basin delineation were obtained. Sub-basins are generated, with a mean elevation of135.52m and a standard deviation of 209.023m. The DEM minimum elevation is 0 m, the highestelevation is 8509 m. Figure 2 displays the DEM model at varying elevations.

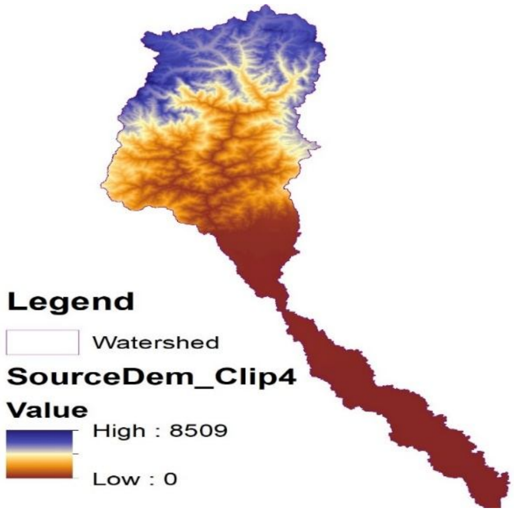

Fig. 2. DEM for the Teesta River Basin

2.2.2 Stream Network

Watershed delineation required the computerized stream network. http://hydrosheds.cr.usgs.gov/index.phpprovides access to the USGS Hydro-SHEDS digital stream network data. Data in different regional extents, kinds, and resolutions are provided by Hydro-SHEDS. The data resolution employed in this study was15s. After being entered into the SWAT model, the Digital Stream Network is shown in Figure 2.

2.2.3 Land use

Changes in land cover have a big impact on the water cycle and floods. According to[16], one of the key factors affecting surface erosion, drainage, and evapotranspiration in a watershed is land use. Data of land cover at a resolution of 10 m was acquired from the Sentinel-2 10-Meter Land Use/Land Cover system of ESRIhttps://livingatlas.arcgis.com/landcover.The value and label of the land use category in the river basins are shown in Table 2. The information is defined as a lookup table and entered as a raster file. Twelve main categories comprise the roughly 80 classifications that make up the Global Land Cover[17].The land cover of Rangpur Station's Teesta Basin is depicted in the map.

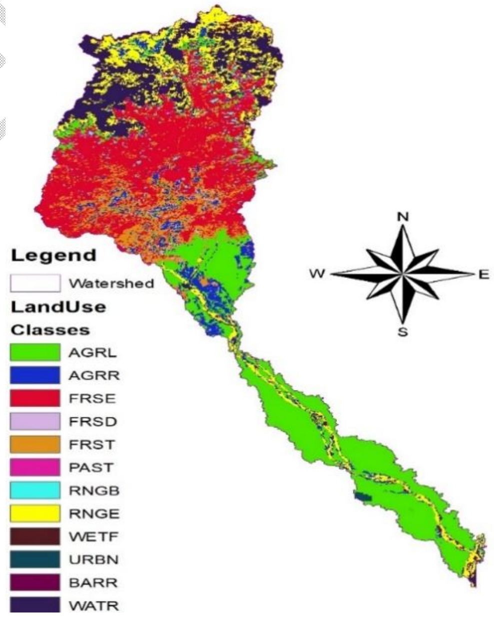

Fig. 3. Major Land-Use in the Teesta River Basin

Table 2. Land-Use of Teesta River Basin

Code	Label	Watershed Area (%)
AGRL	Agricultural Land-Generic	25.12
AGRR	Agricultural Land-Row Crops	7.14
FRSE	Forest-Evergreen	28.64
FRSD	Forest-Deciduous	0.85
FRST	Forest-Mixed	10.48
PAST	Pasture	0.86
RNGB	Range-Brush	1.25
RNGE	Range-Grasses	11.69
WETF	Wetlands-Forested	0.22
URBN	Residential	0.18
BARR	Barren	1.31
WATR	Water	12.27

The value and label of the land use classification in the study region are shown in Table 2. The lookup table is defined by the data input, which is a raster file. There are twelve distinct land use forms in the Teesta River basin (Table 2). Forest-Evergreen (28.64%)covers the majority of the land, followed by Agricultural Land Generic (25.12%) whereasresidential areaoccupies the least amount of land (0.18%).

2.2.4 Soil Data

The physiochemical properties and various soil textures are required by the SWAT model, which makes soil data important. The FAO-UNESCO Global Soil Map is accessed at http://www.fao.org/soils-portal/ . The soil data was entered as a shape file. Once the soil shape file has been supplied, a lookup table will be used to obtain the unique sequential code number (SNUM), which varies from 1 to 6,997 for each soil mapping. Soils are classified into four hydrologic classes based on their hydraulic conductivity such ashydrologic groups A, B, C, and D.

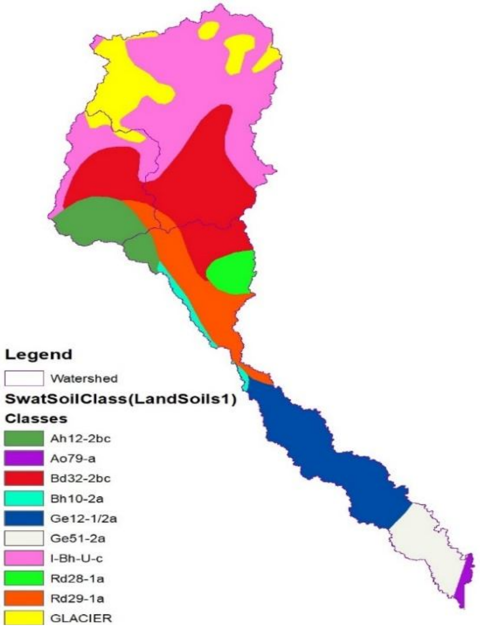

Fig. 4.FAO soil types in the Teesta River Basin

Hydrologic group A has very high rates of infiltration, group B has moderate rates, group C has slow rates of infiltration, and group D exhibits extremely sluggish rates of infiltration-even after being completely wetted. The initial state of the soil and its texture affect surface flow. Soil erosion is more common on barren land than in forest areas due to surface soil erosion. The primary processes that generate the soil are the Teesta River's currents and sedimentation. Rainfall absorption capacity varies throughout soil types, indicating that soil plays a major role in storing precipitation. Compared to loamy and clay soil, sandy soil retains less water. Sand soil is less able to hold water than clay soil. Clay absorbs more water than sand.The Teesta basin area contained the following soil types: Ah12-2bc, Ao79-a, Bd32-2bc, Bh10-2a, Ge12-1/2a, Ge51-2a, I-Bh-U-c, Rd28-1a, and Rd29-1a.

Table 3.FAO soil use

Soils	Area[ha]	Watershed Area (%)
Ah12-2bc	82952.8775	6.76
Bd32-2bc	266379.6501	21.69
Bh10-2a	14773.5379	1.2
Ge12-1/2a	165189.7099	5.71
GLACIER	117487.2623	9.57
I-Bh-U-c	360747.5718	29.38
Rd28-1a	32801.372	2.67
Rd29-1a	108852.2073	8.86

2.2.5 Meteorological data

A tremendous amount of weather data is needed for the SWAT model to work. Meteorological data was obtained using the WATCH Forcing Data approach applied to ERA-Interim reanalysis data (WFDEI). After that, the meteorological data is ready to be entered into the SWAT model based on the location of the weather station and the study region's geographic coordinates. For the SWAT model to function, it needs data on humidity, wind speed, solar radiation, rainfall, and temperature (max and min). One of the main types of input for SWAT's watershed simulation is climate data[18]. Precipitation and temperature data are the only minimally necessary inputs for the SWAT model; all other elements are optional[16]. Meteorological data from2003 to 2020 were used in the investigation. SWAT Meteorological Data applied for watershed modeling are provided here in brief:

- Data time series input: daily data
- Simulation period: (2003 to 2020)
- Rainfall distribution: Daily (mm)
- Maximum and minimum daily temperatures (in□)
- Relative humidity (%): Daily
- Wind speed (m/s): Daily

The weather data definition dialog in the SWAT model is separated into six tabs: temperature, solar radiation, wind speed, relative humidity, rainfall, and weather generator data. The User Weather Stations database or one of the integrated US databases are the two sources from which weather station location and weather generator data are derived. We used temperature and precipitation data from the 1995–2020 time span to create the SWAT model. The model can use daily averaged data that has been examined for a number of years to generate the result, or it can read these inputs straight from the file. The WGEN weather generator model [19]is incorporated to produce climatic data and bridge any gaps in measured records. The weather generator produces precipitation for the day on its own first, then maximum and minimum temperature, wind speed and relative humidity.

2.2.6Hydrological data

Hydrological data entry into the SWAT model is essential. The hydrological data was provided by the Bangladesh Water Development Board[20]. For calibration and validation, the study used hydrological data from 2003 to 2020, mainly water level data. The water level data from the Rangpur station were used for calibration. Water level data collected every 24 hours was a major source of calibration and validation for this investigation.

3. Observed data

Sensitivity analysis of physiographic characteristics in the Teesta River Basin provides important new information about how these features affect hydrological processes and strategies for managing water resources. Analysis of the reaction of important parameters to changes in external factors is done systematically in order to identify important drivers of hydrological variability and their consequences for watershed dynamics. A small overestimation of flow is present in the Teesta River hydrological model, although overall model accuracy is high. The water-related efficiency of base scenarios in the Teesta River basin was analyzed using SWAT data. An essential part of a model's performance is its validation and calibration. The SWAT model is run using data on precipitation, temperature, wind speed, and relative humidity from 2003 to 2020.

3.1 Temperature

The method applied to the weekly stationary generation process in order to produce daily figures for the highest and minimum temperature. The temperature data was measured in °C and was computed on a daily basis, with the average maximum and lowest temperatures being taken into consideration. On the other side, the river discharge is expressed in m^3/s. As the average temperature rises, discharge increases. The average temperature of about 30°C is when discharge is at the highest. Figure 5displays thedischarge and precipitation data of the Teesta basin from 2003 to 2020.

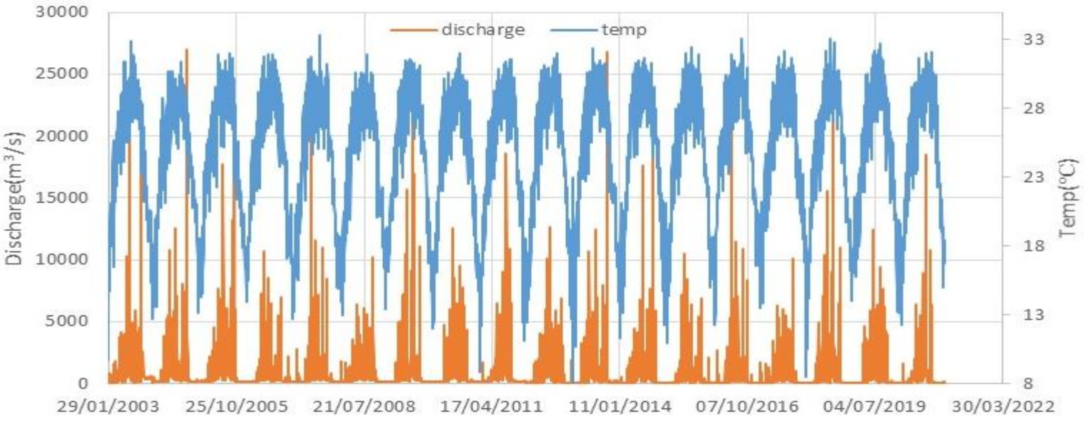

Fig. 5.Effect of temperature on river outflow

3.2Discharge with precipitation

From a hydrological perspective, precipitation is any form of water that reaches the surface of earth. Common forms include dew, hail, rain, and snow. The majority of precipitation in Bangladesh, a tropical nation, only happens as rain. Since precipitation data is the foundation of many hydrological research, hydrologists value precipitation data above everything else.Although precipitation and evapotranspiration are two ways that relative humidity might indirectly affect river discharge, other factors like watershed characteristics, groundwater dynamics, and climatic variables have a greater and more direct impact.

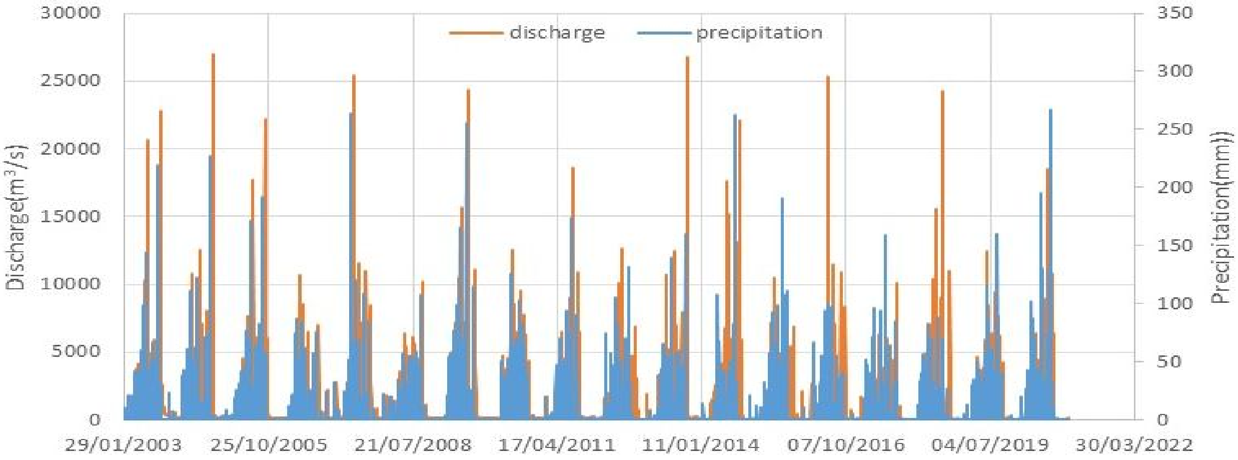

Fig. 6.Comparison between observed discharge andprecipitation

It is clear from Figure 6 that periods of high precipitation coincide with peak discharge, and vice versa. Furthermore, we noticed a slight lag between the peak precipitation and the highest discharge. This is known as the "lag time" and occurs when surface or river flow is occasionally required following precipitation.

4. Swat-Cup for Calibration and Validation

Calibration can be defined as the process of adjusting certain model parameters and variables. In order to align the simulated data with the real data, these values were modified. The primary goal of model calibration is to establish a workable method for determining a set of parameters for a given catchment under given circumstances. Providing the best match values between the simulated and actual stream flows for a specific calibration time was the primary goal of the calibration process.The three essential steps for a successful model implementation are calibration, verification, and validation. To minimize the discrepancy between the simulated and actual flow data, model parameters are adjusted during the calibration process. A model's ability to estimate runoff during times other than those utilized for model calibration is evaluated through model validation. Model verification, is the study of the range of circumstances under which the model will produce outcomes that are deemed acceptable. In many cases, when a model is routinely applied to a gauged watershed, just calibration is necessary.Verification and validation of models are often viewed as unfeasible. Typically, it is the responsibility of the model's developers and researchers to gather important data on these two processes. An explanation of model verification is particularly important for applications to ungagged watersheds when calibration and validation are not possible.In SWAT-CUP, the model was calibrated and validated by taking into account 13 important hydrological factors using the SUFI-2 technique. As advised by the SWAT expert group[21], each parameter was then set to its default lower and upper values. In the end, the SWAT database for stream discharge simulations was updated to include the best fitting parameter values derived from SWAT-CUP. The model's performance was assessed using the RMSE-observations standard deviation ratio (RSR) [22], percentage of bias (PBIAS), coefficient of determination (R^2), and Nash-Sutcliffe efficiency (NSE)[20]. The years 2003 to 2011 and 2012 to 2020 have been chosen, respectively, as the calibration and validation periods. The size and form of the generated hydrographs were more influenced by some parameters.

5. Evaluation of Model Efficiency

Four distinct statistical approaches were used for the calibration and validation: the root mean square error (RMSE), root mean standard deviation ratio (RSR), percent bias (PIBS), the coefficient of determination (R^2), and the Nash and Sutcliffe efficiency (NSE). The strength of the linear relationship between the simulated and observed data is shown by the R^2 value. A normalized statistical technique called the NSE is used to forecast how much noise there will be in relation to the information. When the R^2 and NSE values are at or below 0, the model's prediction is deemed unsatisfactory or inadequate. The model predicts with accuracy when the values are one[21]. For stream flow, a model simulation is generally deemed sufficient if $R^2 > 0.75$ [22]and NSE > 0.50[22]. NSE and R^2 have statistical definitions as follows:

$$R^2 = \left(\frac{\sum_{i=1}^{n}(Q_{obs}-\bar{Q}_{obs})(Q_{sim}-\bar{Q}_{sim})}{\sqrt{\sum_{i=1}^{n}(Q_{obs}-\bar{Q}_{obs})}\sqrt{\sum_{i=1}^{n}(Q_{sim}-\bar{Q}_{sim})}}\right)^2$$

and

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs}-\bar{Q}_{sim})^2}{\sum_{i=1}^{n}(Q_{sim}-\bar{Q}_{obs})^2}$$

where Q_{obs} is the observed data on day i, Q_{sim} is thesimulated output on day i, $\bar{Q}_{obs}$ is the mean observed dataduring study period,$\bar{Q}_{sim}$is the mean simulated data duringstudy period and n is the total number of observed data.

The average tendency of the simulated data to be greater or smaller than their observed counterparts is measured by percent bias (PBIAS) [22]. PBIAS values 0 represent the ideal value; smaller values are more favored. Model overestimation bias is indicated by positive values, and underestimation bias is indicated by negative values. The following formula is used to calculate the PBIAS:

$$PIBS = 100 \times \frac{\sum_{i=1}^{n}(Q_{obs}-Q_{sim})}{\sum_{i=1}^{n} Q_{obs}}$$

RMSE is one of the most popular error index statistics [23]. The following equation illustrates how to calculate RSR, which is the product of the RMSE and the standard deviation of the observation data.

$$RSR = \frac{\sum_{i=1}^{n}(Q_{obs} - Q_{sim})^2}{\sum_{i=1}^{n}(Q_{obs} - \bar{Q}_{sim})^2}$$

RSR ranges from a big positive number to the ideal value of 0, which represents perfect model simulation. Better model simulation performance is associated with reduced RSR and RMSE.

6. Results and Discussion

The discharge of the Teesta River Basin has been measured using the hydrological model SWAT. The evaluation of model performance heavily relies on the calibration and validation of the model. Model development requires sensitivity analysis as a necessary component. The SUFI-2 technique in SWAT_CUP has been used to examine the sensitivity of 13 parameters. Threeparameters-the SCS runoff curve number (CN2.mgt),saturated hydraulic conductivity of the soil lair (SOL_K ().sol) and soil bulk density (SOL_BD().sol)-show the highest sensitivity for the Teesta basin for both the one-at-a-time and global sensitivity procedures.

6.1 Parameter Sensitivity

For the purpose of analyzing parameter sensitivity, we have employed two methods: the global sensitivity approach and the one-at-a-time method. The subsequentsubsections discuss the outcome of both local (one-at-a-time) and global sensitivity.

6.1.1 One-at-a-time sensitivity

The one-at-a-time sensitivity shows how sensitive a variable is to changes in one parameter when all other parameters are held constant at a certain value. The soil parameter, saturated hydraulic conductivity of soil layer (SOL_K().sol) for the Teesta River Basin was determined to be the most sensitive parameter for the one-at-a-time sensitivity analysis. Additional parameters that shown higher sensitivity arerunoff curve number (CN2.mgt)and Manning's n value for the main channel alluvium (CH_N2.rte). The effective hydraulic conductivity in main channel alluvium (CH_K2.rte) isevaluated the very sensitive input parameter using one-at-a-time sensitivity analysis.

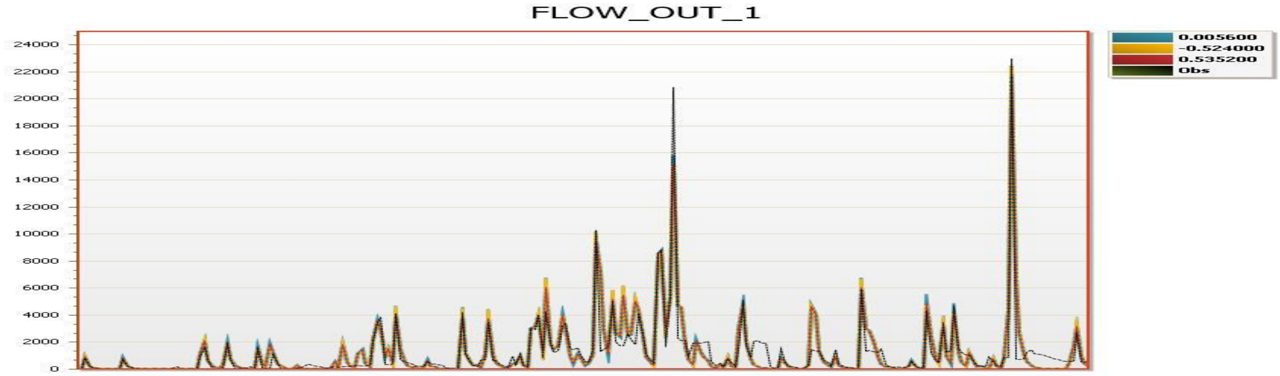

Fig. 7. Sensitivity of saturated hydraulic conductivity (SOL_K()) on discharge for three differentvalues

The simulated discharge is presented for three values of saturated hydraulic conductivity of the soil layer (SOL_K ().sol), with the other values fixed within the designated calibration range by the SUFI-2 process in SWAT-CUP. The dashed black line represents the observed discharge. Because the simulated discharge curve varies for different levels of SOL_K().sol, we can observe that SOL_K().sol is highly sensitive. A rising simulated discharge curve corresponds with growing SOL_K().sol, whereas a lowering simulated discharge curve corresponds with decreasing SOL_K().sol. Thus, one of the sensitive factors influencing the simulated discharge is SOL_K().sol.

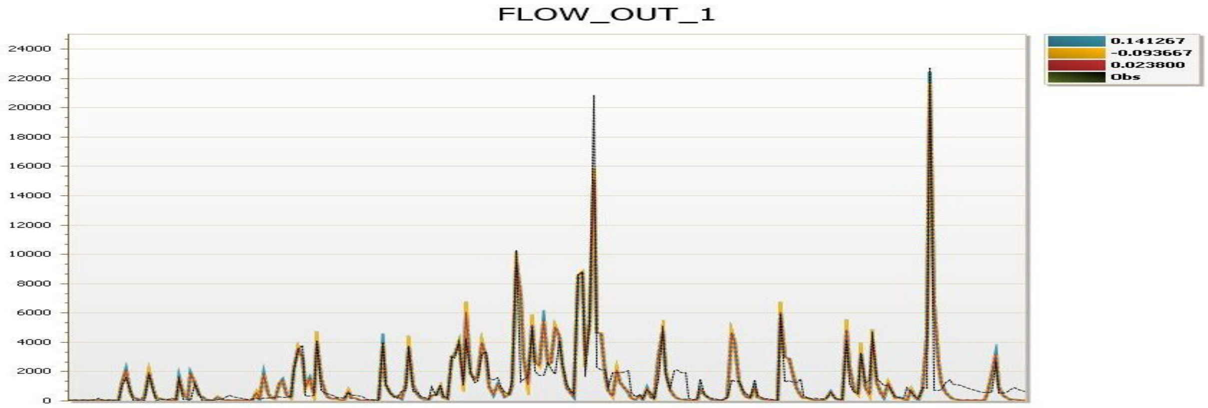

Fig. 8.Sensitivity of coefficient the curve number (CN2) on discharge for three differentvalues

Plotted for three values of coefficient the curve number (CN2), the dashed line represents the observed discharge and the simulated discharge.mgt maintaining others fixed within the designated calibration range using the SWAT-CUP SUFI-2 method. Because the simulated discharge curve varies for varying levels of CN2, we can observe that CN2 is sensitive. One of the sensitive parameters that affects the simulated discharge is CN2.

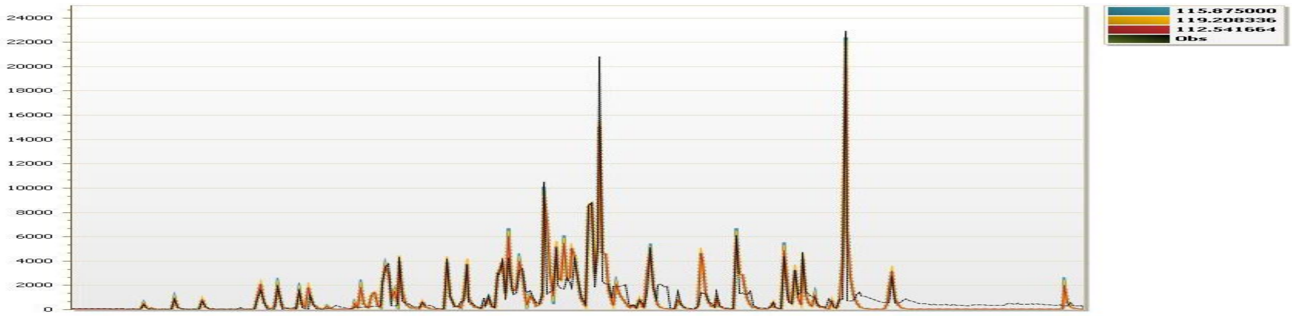

Fig. 9. Sensitivity of effective hydraulic conductivity of channel (CH_K2) on discharge for three differentvalues

Figure 9 demonstrates the significant influence of effective hydraulic conductivity in main channel (CH_K2.rte) on the discharge graph simulation. It is evident that during the pre-monsoon period, simulated discharge rises while CH_K2 falls and vice versa. Simulated discharge increases in the post-monsoon when CH_K2 increases. Therefore, in a one-at-a-time study, CH_K2 is a sensitive parameter.

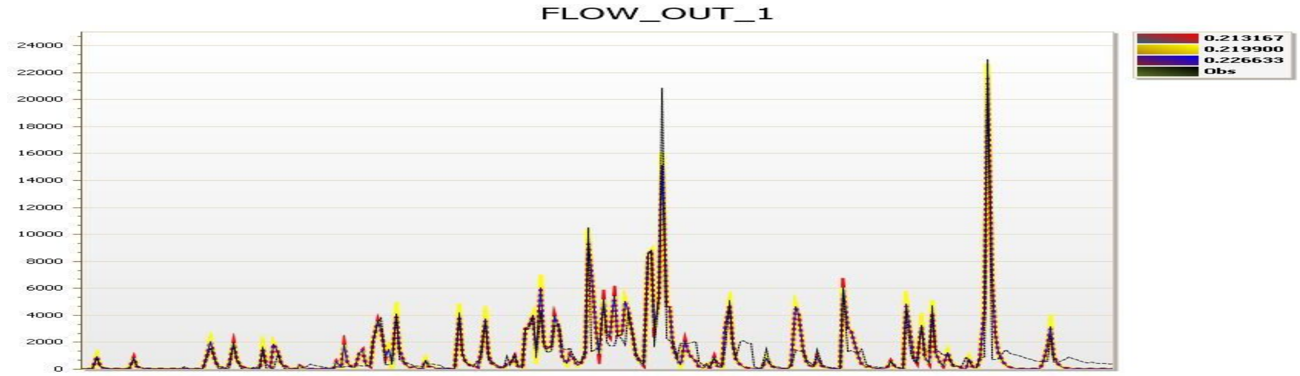

Fig. 10. Sensitivity of Manning's n value for the main channel(CH_N2)on discharge for three differentvalues

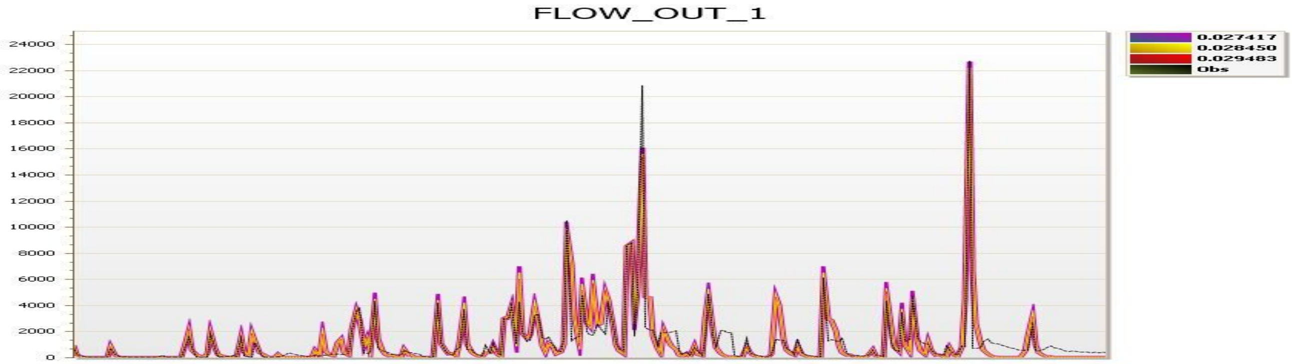

Fig. 11. Sensitivity of soil bulk density (SOL_BD) on discharge for three differentvalues

Figure 11 shows that the soil parameter SOL_BD is also sensitive.

Therefore, under one at a time sensitivity analysis SOL_K, CN2, CH_K2 and CH_N2 are sensitive, whereas other parameters are less sensitive since they have less impact on the simulated discharge.

6.1.2 Global Sensitivity

Based on the t-statistic and p-value of the global sensitivity of parameters are analysed. Figure 12 indicated the most sensitive input parameters. The more sensitive the parameter in this study, the greater the absolute value of the t stat and the smaller the p-value[24].

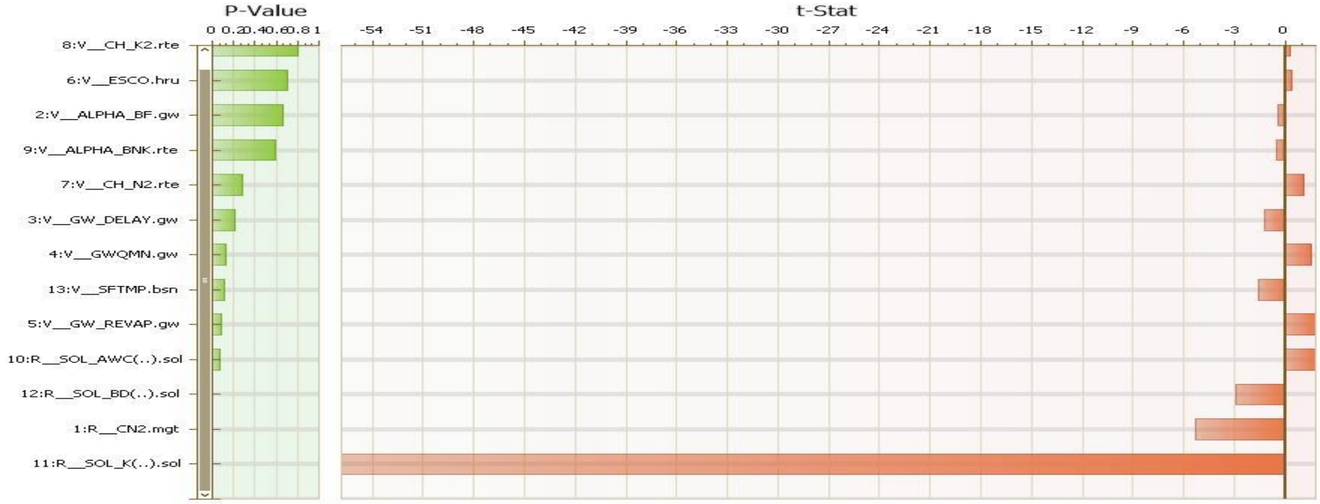

Fig. 12.Global sensitivity by t-stat and p-value

Approximately seven parameters are seemed sensitive in the research region, according to the results of the assessment of the global sensitivity procedure. Table highlights the output. The top four input parameters in the study area are saturated hydraulic conductivity of soil layer (SOL_K().sol), the runoff curve number (CN2.mgt), soil bulk density (SOL_BD().sol) and soil water holding capacity (SOL_AWC().sol).

In a few steps, the overall outcomes of global sensitivity and one at a time can be explored. In both scenarios, three parameters SOL_K().sol, CN2.mgt and SOL_BD().sol show consistent and sensitive behaviour. In a local sensitivity analysis, CH_K2 is the sensitive parameter. Conversely, in the global sensitivity analysis, Saturated hydraulic conductivity of soil layer SOL_K().sol is the most sensitive parameter. Only one technique is sensitive to four criteria. In the one-at-a-time approach, CH_K2.rte is highly sensitive; yet, is not sensitive in the global sensitivity technique.

6.2Calibration and Validation result in daily simulation

Model calibration aims to give a repeatable method for choosing a set of parameters for a given catchment under particular circumstances. Finding the values that best matched the simulated and actual stream flows for a certain calibration time was the main objective of the calibration. Two time periods were designated: 2003–2011 for calibration and 2012–2020 for validation. The figure below shows the calibration graph along with real and simulated data.

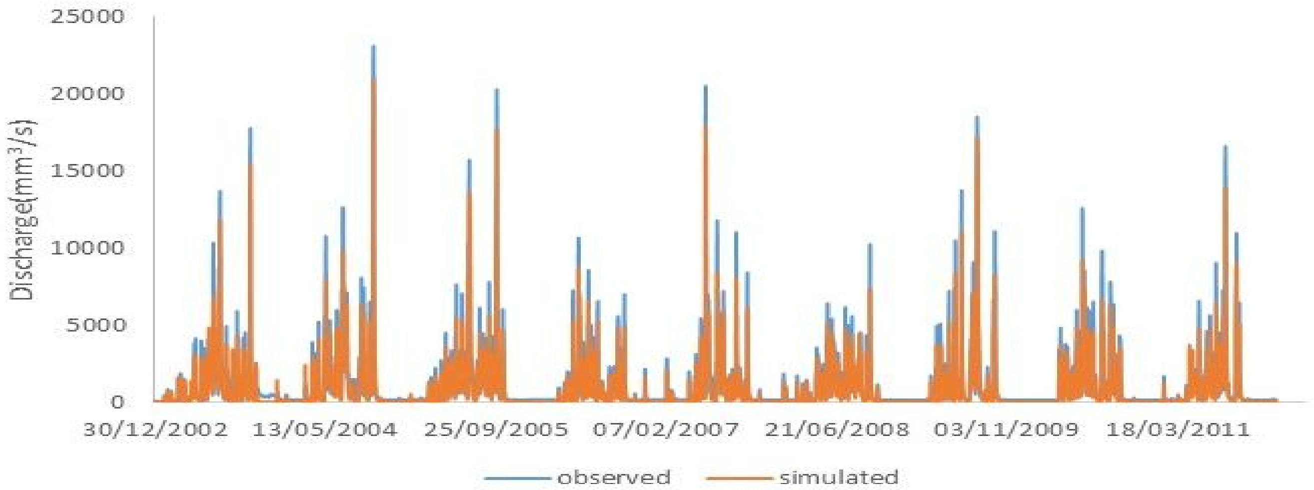

Fig. 13.Daily discharge calibration (2003-2011)

With the coefficient of determination, R^2=0.90(0 ≤ R^2≤ 1), Nash–Sutcliffe Efficiency index (NSE)=0.89(0≤NSE ≤1), percent bias (PBIAS) = 6.89, and RMSE-observation standard deviation ratio (RSR) = 0.45, we may conclude from the above figure that the calibration result is quite acceptable.
The validation graph along with observed data and simulated data has been shown in following figure:

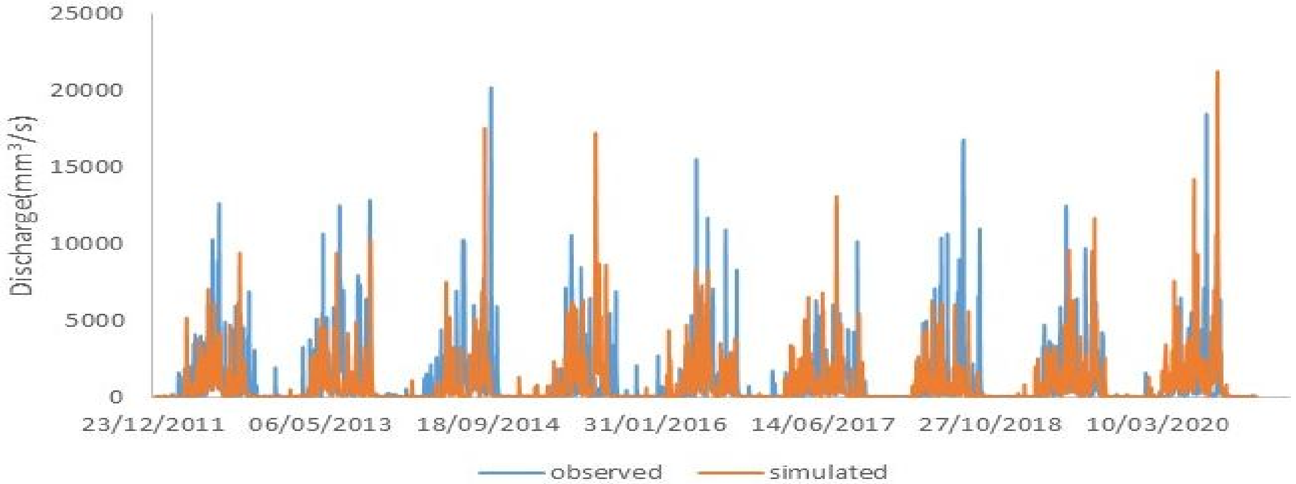

Fig. 14.Daily discharge validation (2012-2020)

Evaluation of the performance of the model was done by comparing the observed andsimulated stream flow for Teesta River at Rangpur station, for validation period as 2012 to2020 years.Based on the aforementioned figure, we can conclude that the validation result is acceptable since the RMSE-observations standard deviation ratio (RSR) = 0.54, the percent bias (PBIAS) =10.09, the coefficient of determination, R^2 = 0.70(0 ≤ R^2 ≤1), and the Nash–Sutcliffe Efficiency index (NSE) =0.66(0 ≤ NSE ≤ 1).For the calibration period, the NSE value was 0.89, which was deemed acceptable. The NSE value of > 0.65 is satisfactory for the SWAT model's calibration period. With a validation NSE of 0.66, this is an adequate performance.

Table 4. Model performance statistics for calibration and validation period of the Teesta basin

	NSE	PBIAS	RSR	R^2
Calibration	0.89	6.89	0.45	0.90
Validation	0.66	10.09	0.54	0.70

Table 5. General performance ratings of statistical test

Performance Rating	NSE	PBIAS	RSR	R^2

Very Good	0.75<NSE≤1	PBIAS<±10	0.0<RSR≤0.5	$0.75<R^2\leq 1$
Good	0.65<NSE≤0.75	±10<PBIAS<±15	0.5<RSR≤0.6	$0.65<R^2\leq 0.75$
Satisfactory	0.5<NSE≤0.65	±15<PBIAS<±25	0.6<RSR≤0.7	$0.5<R^2\leq 0.65$
Unsatisfactory	NSE≤0.5	PBIAS>±25	RSR>0.7	$R^2\leq 0.5$

Tables 4 and 5 can be compared to see that the model performance statistics R^2, NSE, RSR, and PBIAS are within an acceptable range for both calibration and validation. The values of the model performance test show that the output ofmodel is excellent and suitable for use. In light of this, calibration and validation results showed that the model does a very good job of mimicking discharge data.

7. Conclusions

The discharge ofthe Teesta river basin, the most significant basin for the northern region of Bangladesh, is simulated utilizing a variety of hydrologic parameters using the Arc-GIS enabled SWAT model. In order to show model performance that can yield findings that are acceptable, this research tests the utilization of hydrological data using Arc-SWAT in conjunction with SWATCUP software. Various open-source organization data and satellite-based data were employed in this investigation. In addition, other parameters included in the governing equation were employed to modify the value. The model agrees with the observed value most of the time; occasionally, it overestimates and occasionally underestimates the value. Every time, the statistical fitting values matched well, but occasionally they did not match the best fit value. Sensitivity analysis in the research region was successfully carried out by the SWAT-CUP algorithms. The most sensitive parameters in terms of both case global and local sensitivity for the Teesta River basin are determined to be CN2.mgt,SOL_K ().sol and SOL_BD().sol. In the one-at-a-time sensitivity analysis, CH_N2.rte and CH_K2.rte exhibit good sensitivity, but not so much in the global sensitivity technique. In the global sensitivity methodology, CH_K2.rte is insensitive, but it is highly sensitive in the one-at-a-time method.Therefore, CN2.mgt,SOL_K ().sol and SOL_BD().sol.for the Teesta Basin indicate the most sensitive parameters. For other tropical watersheds with comparable geographical patterns, it is similarly advised to use these parameters. These sensitivity parametersare mostly affecting the flood frequency that allowed us to forecast future flooding. SWAT-CUP increases user confidence in the model predictive capabilities by calibrating stream flow simulations and analyzing parameter sensitivity. This reduces uncertainty and maximizes the effectiveness of the model's application. Ultimately, it can be said that this model can be used to forecast the flow of the Teesta River in situations where it is not feasible to measure the discharge due to a lack of funds or expertise. Others river basins in Bangladesh can also adopt this approach which is quite suitable.Sediment and nutrient of the Teesteriver catchment can be simulated by the SWAT model and compared with the observed data when thesuspended sediment concentration data are available from a turbidity meter.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

References

[1] Afroz R., Rahman M.A., "Transboundary River Water for Ganges and Teesta Rivers in Bangladesh: An Assessment," *Global Science and Technology Journal,* pp. 100-110, Vol.1 July 2013.
[2] Khan I., Ali M., "Potential Changes to the Water Balance of the Teesta River Basin Due to Climate Change," *American Journal of Water Resources,* vol. 7, pp. 95-105, 2019.doi: 10.12691/ajwr-7-3-2
[3] Mandal S. P.,Chakrabart A., "Flash flood risk assessment for upper Teesta river basin: using the hydrological modeling system (HEC-HMS) software," *Modeling earth systems and environment,* 2016. doi: 10.1007/s40808-016-0110-1
[4] Sharma A., Goyal M.K., "Assessment of the changes in precipitation and temperature in Teesta River basin in Indian Himalayan Region under climate change," *Atmospheric Research,* 2019.doi:10.1016/j.atmosres.2019.104670
[5] Gupta V., Chauhan N., Penna I., Hermanns R., Dehls J., Sengupta A., Bashin R.K., "Geomorphic evaluation of landslides along the Teesta river valley, Sikkim Himalaya, India," *Geological Journal ,* 2022.doi: 10.1002/gj.4377
[6] Hatui K. , "A study of geomorphic parameters of the upland catchment basin of tista river using gis-rs techniques," *Indian Statistical Institute,* 2009.
[7] Rahman S., Islam AKM S., "Impact of Climate Change and Land Use Land Cover Change on Stream Flow of the Teesta River Basin under CMIP6 Climate Scenarios," 2024. doi:10.21203/rs.3.rs-3844543/v1

[8] Krishnakumar A., Jose J., Kaliraj S., Aditya S.K., Krishnan K.A., "Assessment of the impact of food on groundwater hydrochemistry and its suitability for drinking and irrigation in the River Periyar Lower Basin, India", *Environmental Science and Pollution Research* (2022) 29:28267–28306. doi: 10.1007/s11356-021-17596-y

[9] Kumar M.R., Krishnan K.A., Vimexen V., Faisal A.K., Mohind M., Arun V., ‘‘Heavy metal impression in surface sediments and factors governing the fate of macrobenthic communties in tropical estuarine ecosystem, India’’, *Environmental Science and Pollution Research* (2022) 29:38567–38590. doi: 10.1007/s11356-021-18394-2

[10] Saranya P., Krishnakumar A., Kumar S., Krishnan K.A., ‘‘Isotopic study on the effect of reservoirs and drought on water cycle dynamics in the tropical Periyar basin draining the slopes of Western Ghats’’, *Journal of Hydrology*, February 2020. doi:10.1016/j.jhydrol.2019.124421

[11]Akhtera S., Eibeka K.U., Islama S., Islama A.R.M.T., Chub R., Shuangheb S.,‘‘Predicting spatiotemporal changes of channel morphology in the reach of Teesta River, Bangladesh using GIS and ARIMA modeling’’, *Quaternary International* 513 (2019) 80-94, doi:10.1016/j.quaint.2019.01.022

[12] Gassman P. W., Sadeghi A.M.,Srinivasan R., "Applications of the SWAT Model Special Section:Overview and Insights," *Journal of Environmental Quality43:1–8 (2014)*.doi:10.2134/jeq2013.11.0466

[13] Moriasi D.N., Arnold J.G.,Liew M.W.V., Binger R. L., Harmel R. D., Veith T. L., "Model Evaluation guidelines for systematic quantification of accuracy in watershed simulation," *Transactions of the ASABE,* 2007.doi: 10.13031/2013.23153

[14] Santhi C., Arnold J. G., Williams J. R., Dugas W. A., Srinivasan R., Hauck L.M., "Validation of the SWAT model on a large river basin with point and nonpoint sources," *J. American Water Resources Asso.,* 2001.doi:10.1111/j.1752-1688.2001.tb03630.x

[15]Gassman P. W., Reyes M. R., Green C. H., Arnold J. G., "The soil and water assessment tool: historical development, applications, and future research directions" *Transactions of the ASABE. 50(4): 1211-1250. doi: 10.13031/2013.23637*

[16] Ghoraba S. M., "Hydrological modeling of the simly dam watershed (pakistan) using gis and swat model," *Alexandria Engineering Journal ,* 2015.doi:10.1016/j.aej.2015.05.018

[17]Poméon T., Diekkrüger B., Springer A., Kusche J., Eicker A.,"Multi-Objective validation of swat for sparsely-gauged west african river," *Water,* 2018.doi:10.3390/w10040451

[18]Chu T.W.,Shirmohammadi A., "Evaluation of the swat model’s hydrology component in the piedmont physiographic region of maryland.," *Transactions of the ASAE,* pp. 1057-1073, 2004. doi: 10.13031/2013.16579

[19]Sharpley A.N. and Williams J.R., "EPIC-Erosion Productivity Impact Calculator: 1",*Agricultural Research Service,* 1990.

[20]"Bangladesh Water Development Board (BWDB)," Available: http://www.hydrology.bwdb.gov.bd

[21] Neitsch S.L, Arnold J. G., Kiniry J.R., Williams J. R., "Soil and water assessment tool theoretical documentation version 2009," *Texas Water Resources Institute,* 2011.https : / /hdl .handle .net /1969 .1 /128050

[22] Gupta H.V., Sorooshian S., Yapo P. O., "Toward improved calibration of hydrologic models: Multiple and noncommensurable measures of information," *Water Resources Research,* 1998.doi: 10.1029/97WR03495

[23]Hodson T. O.: Root-mean-square error (RMSE) or mean absolute error (MAE): when to use them or not, Geosci. Model Dev., 15, 5481–54872022. doi:10.5194/gmd-15-5481-2022

[24]Abbaspour K. C., "Swat calibration and uncertainty programs-a user manual," *Swiss Federal Institute of Aquatic Science and Technology: Eawag,* 2015.

[25]Widianto, Luthfi, Zahidah Hasan, IzzaMahdianaAprilliani, and HetiHerawati. 2020. “Physical and Chemical Water Quality of Cirata Reservoir in Cianjur Regency Area”. Asian Journal of Geological Research 3 (3):159-65. https://journalajoger.com/index.php/AJOGER/article/view/103

[26] https://www.sciencedirect.com/science/article/pii/S2095633917302496

[27] https://link.springer.com/article/10.1007/s12517-018-3870-2