Impact of Land Use Changes in Teesta Catchment bySoil Water Assessment Tool

ABSTRACT

The Soil and Water Assessment Tool (SWAT) is a comprehensive, publicly available simulation model use to assess the effect of land use and land cover changes on water, soil erosion, and chemical yields of agriculturein catchments which is developed by the USDA Agricultural Research Service. SWAT models soil erosion and sediment transport, providing insights into how land management practices influence soil loss and sedimentation in water bodies. The Teesta basin has a significant soil erosion issue due to deforestation, excessive grazing, and agricultural expansion; specifically, the cultivation of unproductive peripheral areas and steep slope terrains. The SWAT model is used in this study to quantify streamflow and evaluate the resulting sediment yields. In this context, SWAT is utilized to simulate runoff and to estimate sedimentation abdicate from the Teesta watershed as a result of arrive utilize changes. The SWAT model is calibrated and approved for river flowfor extendedvalidation periods. The Consecutive Vulnerability Fitting(SUFI2) worldwide affectability strategy inside SWAT Calibration and Vulnerability Procedures (SWAT-CUP) was utilized to distinguish the foremost touchy streamflow parameters. The model satisfactorily simulated stream release from the watershed. The model execution was decided with distinctive measurable strategies. The study revealed that both streamflow and average overland sediment yield in the waershed have risen over the observation period. The increased runoff rates could result in severe and frequent flooding, poorer water quality, and diminished crop yields. Consequently, it is essential to implement thorough water management strategies to mitigate surface runoff in the catchment area. This marks the first application of the SWAT model to the Teesta catchment to measure the sediment yield. Changes of land use and land cover has impact on sediment yield; increase of residential land increases sediment yield. The findings suggest that, with minimized uncertainties, a properly calibrated SWAT model can produce reliable hydrologic simulations concerning land use, which is beneficial for water and environmental resource managers, as well as policy makers and decision makers.

Keywords:*SWAT, Teesta,Land Use, Streamflow, Sediment,Calibration, Validation*

1. INTRODUCTION

Land use and ecosystems are closely intertwined, with each influencing the other in significant ways. Land use changes are key contributors of discharge, soil, and air pollution [1], which significantly influences the health of rivers in catchments.Land use refers to the various ways in which human activities utilize the land. Common land uses include agriculture, urban development, forestry, and industrial activities. Each type of land use has distinct effects on the environment, influencing everything from soil health to water resources and biodiversity. According to the study [2], changes in land use and land cover can alter river flow patterns because of the temporal shifts in runoff distribution. In developing countries like Bangladesh, where economies heavily rely on agriculture and population growth is rapid, changes in land use and land cover are quite prevalent [3]. Clearing vegetation for agricultural land makes soil highly vulnerable to significant erosion by wind and water. This erosion decreases soil fertility, making it less suitable for farming, and results in the transport of large amounts of nitrogen, phosphorus, and sediments into streams. Such runoff can lead to increase sediment yield, water turbidity, eutrophication, and coastal hypoxia in wetlands and rivers. Additionally, the use of agricultural chemicals like herbicides, pesticides, and synthetic fertilizers in modernized agriculture has significantly raised pollution levels in surface waters and contaminated groundwater through runoff and leaching. This pollution is often harmful to both aquatic life and humans, with effects that can extend far beyond the immediate area [4].

The Teesta River in Bangladesh, a key water source for the Rangpur district, has undergone significant land use and land cover(LULC) changes over the years. The effects of LULC changes in the Teesta Basin of Bangladesh are significant and multifaceted. Deforestation, agricultural expansion, and urbanization have altered river flow patterns, increased runoff, and heightened soil erosion, leading to sedimentation in the river. This sedimentation has degraded water quality and exacerbated flooding, while runoff carries pollutants and nutrients, causing eutrophication and water turbidity. Additionally, habitat destruction has reduced biodiversity and disrupted ecosystem services such as water filtration and soil stabilization. These changes underscore the need for effective land management and conservation strategies to address the environmental challenges in the Teesta Basin.

Water resource management and land use patterns are intrinsically connected. At the catchment level, different land uses-such as agriculture, forests, urban areas, and industrial zones affect both the quantity and quality of water resources. Ongoing monitoring of water quality is often costly, labor-intensive, and occasionally challenging to perform. Various hydrologic and water quality simulation models have been created to assess how differentland use practices affect water resources. The outcomes from these models assist policymakers and decision-makers in identifying cost-effective land management and conservation strategies to preserve water resources for both present and future populations amid a changing climate. The Soil and Water Assessment Tool (SWAT) is one such model used for these purposes [5-7]. The semi-distributed SWAT model is a continuous-time model that runs on a daily basis and is applied at the river basin scale. It is designed to assess and forecast the effects of land management practices over extended periods on water, sediment, and agrochemical yields in large, complex catchments with diverse soils, land uses, and management conditions [8-9]. The SWAT model has been enhanced with advanced routing and pollutant transport features, such as the effects of reservoirs, point sources, ponds, wetlands, and septic tanks, as well as improved sediment routing routines. This versatile model is used globally to assess water quality and hydrological issues across different watershed scales and environmental conditions, supporting informed policy decisions and effective watershed management [10-12].

Assessing the effects of land use and land cover changes on hydrology is the foundation for managing watersheds and restoring their ecology[13]. SWAT model is used to estimate the discharge in Teesta [14 -15], Meghna [16] and Khoai watershed [17] of Bangladesh. Use of SWAT model to measure the effect of land use changes in Bangladeshi watershed is not noticeable. In this study, the SWAT model is applied to measure river flow and also to estimate the amount of sediment yield from the Teesta watershed as a result of land use and land cover changes. The outcomes from these models assist policy and decision makers in identifying cost-effective land management and conservation strategies to preserve water resources for both present and future populations amid a changing climate for sustainable development.

2. Material and Methods

2.1. Study Area

The Teesta River is a 414 kilometers (257 miles) long river that rises in the Pauhunri Mountain of the Eastern Himalayas, located on the boundary of Sikkim, India, and Tibet.The Teesta River flows through the Indian states of Sikkim and West Bengal before entering Rangpur division of Bangladesh[18]. The Teesta River in Bangladesh can be pinpointed on a map with approximate coordinates: Latitude: 25.6° N, Longitude: 89.0° E. These coordinates are roughly centered along the river's course.The Teesta river basin, a significant River Basin of Bangladesh, is our interest of study area. The gauging station in this basin is located at Kaunia where water level is measured. Land of this basin covered by 12 different types of land use and the types of soils are found along the watershed include: Alluvial Soils, Floodplain Soils, Clayey Soils, Acidic Soils, Saline Soils, Alkaline Soils. These soil types reflect the varying conditions influenced by the dynamics of river and local environmental factors. The soils along the Teesta River are predominantly alluvial, enriched by periodic deposits of silt and organic matter from seasonal flooding. These soils are generally fertile, consisting of loams and silty loams that are well-suited for agriculture. In some areas, clayey soils are present, with high water-holding capacity but potential drainage issues. The region also features slightly acidic soils and, occasionally, saline or alkaline soils near poor-drainage zones. Effective soil management, including proper irrigation and fertilization, is crucial to maintaining soil health and productivity in this dynamic environment.

Agriculture along the Teesta River is heavily reliant on the fertile alluvial soils deposited by the seasonal flooding of river. The region supports a diverse range of crops, including rice, jute, potatoes, and various vegetables, benefiting from the rich, nutrient-laden sediments of river. The availability of water from the Teesta is critical for irrigation, especially during dry periods. However, challenges such as periodic flooding, water management issues, and soil salinity in some areas require careful management to sustain agricultural productivity and ensure food security in the region. The area of Teesta river catchment for this study is shown in Fig. 1.

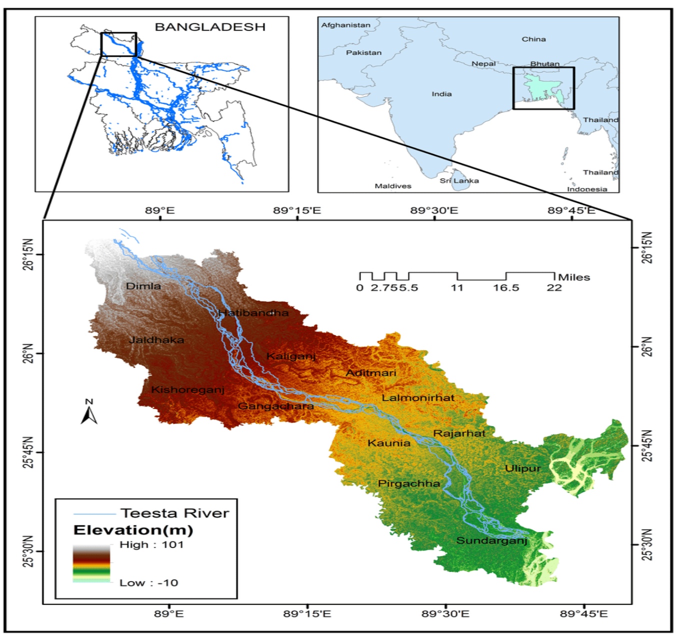

Fig.1. Teesta Watershed [19]

2.2. Data Used for SWAT model

Data used in this research are the Digital Elevation Model (DEM) of Bangladesh, land use and land cover data, soil data, hydrological and meteorological data of the Teesta study area.

2.2.1. Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) provides detailed elevation data for every point within a specific area. By processing this DEM, the study was able to determine topographical features, including flow direction, flow accumulation, stream network generation, and the delineation of watersheds, sub-basins and hydrological response unit (HRUs). This study utilizes a 90-meter resolution DEM from the Shuttle Radar Topographic Mission (SRTM), available for download at https://srtm.csi.cgiar.org/srtmdata/. The SRTM 90m DEMs possess a resolution of 90m at the equator and are available in mosaicked 5-degree by 5-degree tiles for convenient download and utilization. All are generated from a seamless dataset to facilitate easy mosaicking. The DEM of the Teesta River basin ranges from a minimum elevation of 10 meters to a maximum of 8,806 meters which indicates the higher gradient of this basin.

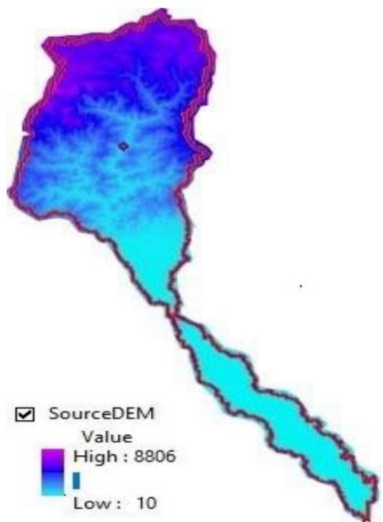

Fig. 2. DEM for the Teesta River Basin

2.2.2. Land Use and Land Cover Data

One of the key elemnts affecting soil erosion, drainage, and evapotranspiration in a watershed is land use and land cover [20]. Land cover changes significantly affect the water cycle and flood dynamics. For this study, land cover data at a 10 m resolution was sourced from the Sentinel-2 10-Meter Land Use/Land Cover system provided by ESRI, available at https://livingatlas.arcgis.com/landcover. The land use categories and their values are detailed in Table 1, organized into a lookup table and provided as a raster file. The Global Land Cover dataset includes twelve primary categories, encompassing approximately 80 classifications [21] for the Teesta watershed. Table 1 shows the land use scenarios of this watershed. Most of the land is covered by evergreen forest (28.64%), second largest portion (25.12 %) land is used for agricultural purpose followed by water (12.27 %), range-grasses (11.67 %) and mixed forest (10.48 %) respectively. The lowest portion of land of this study area is used for residential purpose (0.18 %). In this study the effect of the changes of land uses/land cover on discharge and sedimentation are discussed in latter sections.

Table 1. Land-use of Teesta River Basin

Code	Label	Area (%)
AGRL	Agricultural Land Generic	25.12
AGRR	Agricultural Land Row Crops	7.14
BARR	Barren	1.31
FRSE	Forest Evergreen	28.64
FRSD	Forest Deciduous	0.85
FRST	Forest Mixed	10.48
PAST	Pasture	0.86
RNGE	Range Grasses	11.69
RNGB	Range Brush	1.25
WATR	Water	12.27
WETF	Wetlands Forested	0.23
URBN	Residential	0.18

Land cover and land use of the Teesta catchment in Rangpur Division is illustrated in Fig. 3.

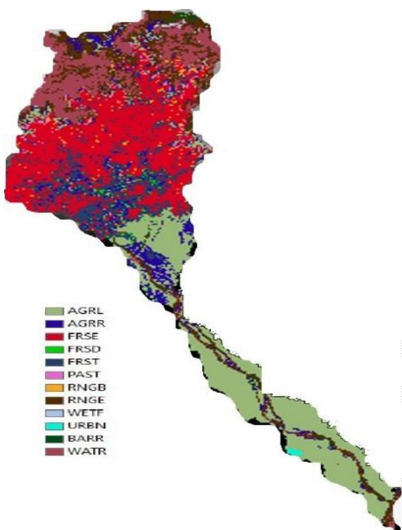

Fig. 3. Land use and land cover map of the Teesta River Catchment

2.2.3. Soil Data

The SWAT model requires soil data that includes physiochemical properties and various soil textures, making soil information crucial. The FAO-UNESCO Global Soil Map, available at http://www.fao.org/soils-portal/, provides this data. The soil information was input as a shape file. After supplying the soil shape file, a lookup table is used to assign a unique sequential code number (SNUM), which ranges from 1 to 6,997 for each soil type. Soils are categorized into four hydrologic classes (A, B, C, and D) based on their hydraulic conductivity. Hydrologic group A features very high infiltration rates, while group B has moderate rates. Group C exhibits slow infiltration, and group D shows extremely slow infiltration, even when fully saturated. The initial soil condition and texture influence surface flow. Erosion is more prevalent on barren land compared to forested areas due to surface soil erosion. The main processes contributing to soil formation are the currents and sedimentation of Teesta River. The capacity of soil to absorb rainfall varies by soil type, highlighting the critical role soil plays in precipitation storage. Sandy soil retains less water than loamy or clay soil, with sand being less water-retentive compared to clay. The Teesta basin includes 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 which are depicted in Fig. 4 and Table 2.

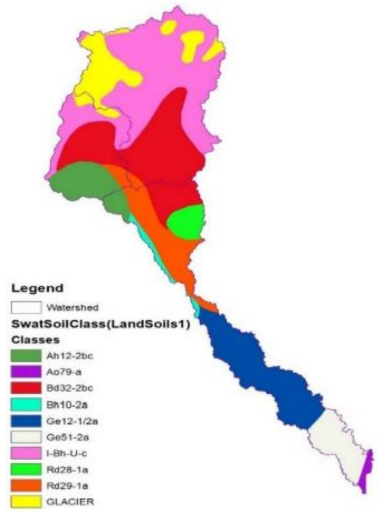

Fig. 4. Soil types of Teesta River Catchment

Table 2: Soil types of the Teesta River Catchment

Soils	Area[ha]	Area (%)
Ah12-2bc	99514	6.76
Ao79-a	10271	0.7
Bd32-2bc	319561	21.69
Bh10-2a	17723	1.2
Ge12-1/2a	198169	13.45
Ge51-2a	84172	5.71
GLACIER	140943	9.57
I-Bh-U-c	432769	23.38
Rd28-1a	39350	2.67
Rd29-1a	130584	8.87

2.2.4 Meteorologicaland HydrologicalData

The SWAT model requires a significant amount of weather data to operate effectively. Meteorological data are obtained through the WATCH (WATer and global CHange) Forcing Data approach, which utilizes ERA-Interim reanalysis data (WFDEI). This data is then prepared for input into the SWAT model, considering the location of weather stations and the geographic coordinates of the study area. To run the SWAT model, data of humidity, wind speed, solar radiation, rainfall, and temperature (both minimum and maximum) are necessary. Climate data is a crucial component for SWAT watershed simulation [22]. Meteorological data from 2003 to 2020 are used in the investigation. In this study metrological data are collected from weather station of this watershed. SWAT Meteorological Data applied for watershed modeling are provided here in brief:

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

The weather data definition interface in the SWAT model is separated into six tabs: rainfall, relative humidity, wind speed, temperature, solar radiation, and weather generator data. Weather station locations and generator of weather data are sourced either from the User Weather Stations database or from one of the integrated US databases. For the SWAT model, temperature and precipitation data spanning from 1995 to 2020 were utilized. The model can either process daily averaged data from multiple years to produce results or directly read inputs from the file. The WGEN weather generator model [23] is used to produce climatic data and fill in any gaps in the measured records. It first generates daily precipitation, followed by minimum and maximum temperatures, relative humidity, andwind speed.Muskingum or the variable storage coefficient methodis used to compute the flow routing in the river channels. In the SWAT model the total water entering into channels in each day from every HRU is calculated by the following equation

$$Q_{flow} = \left(Q_{surf} + Q_{lat} + Q_{gw}\right) \times HRU_{area}$$

here Q_{flow}(mm^3)is total water entering into the channel, Q_{surf}(mm)is surface runoff, Q_{lat}(mm)is lateral flow yield, Q_{gw}(mm) is groundwater yield and HRU_{area}(mm^2)is the HRU area. The SWAT model uses the Modified Universal Soil Loss Equations (MUSLE) to calculate soil erosion at the HRU level.To calculate soil erosion on the catchment slope, the MUSLE is

$$Sed = 11.8\left(Q_{surf} . q_{peak} . area_{hru}\right)^{0.56} . K_{USLE} . C_{USLE} . P_{USLE} . CFRG$$

hereSed is sediment load on a certain day(metric tons),$Q_{surf}$is surface runoff volume (mmH_2O/ha), q_{peak} is peak runoff rate (m^3/s),$area_{hru}$is the area of the HRU(ha), K_{USLE} is USLE soil erodibility factor, $C_{USLE}$is USLE cover and management factor, P_{USLE} is USLE support practice factor, LS_{USLE} is USLE topographic factor and CFRG is coarse fragment factor.

2.3 The SWAT Model Setup

The model utilizes commonly accessible input data, including Digital Elevation Model (DEM), land use data, soil data, and climatic data, as outlined in Section 2.2. For this study, the hydrological process was modeled using ArcSWAT, an extension of the SWAT model designed for ArcGIS software [24]. We installed ArcSWATv2012.10.1.18 in ArcGISv10.3 after downloading it from the website (http://swat.tamu.edu/software/arcswat/).Using the DEM, the catchment was initially delineated in the model setup.Within the sub-basin, HRUs are grouped land areas made up of distinct combinations of land cover, soil, slope, and management[11]. The SWAT model was run on daily basis for a period of sixteen years from 1993 to 2020 with a warm up period of ten years.

2.4 Calibration and Validation of the Model

Calibration involves adjusting specific model parameters and variables to align simulated data with real-world observations. The main objective of model calibration is to develop a reliable method for selecting a set of parameters for a given catchment under specific conditions, ensuring the closest match between simulated and observed stream flows for a designated calibration period. Effective model implementation relies on three key steps: calibration, verification, and validation. During calibration, model parameters are fine-tuned to minimize the differences between simulated and actual flow data. Validation assesses the model's accuracy in predicting runoff for periods outside the calibration timeframe. Verification examines the range of conditions under which the model yields acceptable results. In many practical applications involving gauged watersheds, only calibration is needed, as verification and validation may not always be feasible. Typically, the responsibility for gathering detailed information on these processes falls on the model developers and researchers. Verification is especially crucial for applications in ungauged watersheds, where calibration and validation are not feasible. In the SWAT-CUP, calibration and validation were conducted using the SUFI-2 technique, taking into account 13 key hydrological factors. Each parameter was initially set to its default lower and upper bounds as recommendations of the SWAT expert group [25]. Ultimately, the SWAT database for stream discharge simulations was updated with the optimal parameter values obtained from SWAT-CUP. The performance of model was evaluated using several metrics, including the RMSE-observations, standard deviation ratio (RSR) [26], percentage of bias (PBIAS), the coefficient of determination (R^2), and Nash-Sutcliffe efficiency (NSE) [27]. The periods from 2003 to 2011 and 2012 to 2020 were selected for calibration and validation, respectively. Some parameters had a greater impact on the shape and magnitude of the generated hydrographs.

2.5 Evaluation of Model Performance

Four different statistical methods were employed for calibration and validation: root mean square error (RMSE), root mean standard deviation ratio (RSR), percent bias (PBIAS), the coefficient of determination (R^2), and Nash-Sutcliffe efficiency (NSE). The R^2 value indicates the strength of the linear relationship between the simulated and observed data. NSE is a normalized statistical measure used to evaluate the proportion of noise relative to the signal in the model's predictions. If the R^2 is zero and NSE value is negative, the model's predictions are considered unsatisfactory. Conversely, when these values are close to one [25], the model is considered highly accurate. For streamflow simulations, the model performance is typically deemed acceptable if R^2 is greater than 0.75 and NSE exceeds 0.50 [26]. The statistical definitions of NSE and R^2 are as follows:

$$R^2 = \left(\frac{\Sigma(Q_{obs} - \bar{Q}_{obs})(Q_{sim} - \bar{Q}_{sim})}{\sqrt{\Sigma(Q_{obs} - \bar{Q}_{obs})}\,\sqrt{\Sigma(Q_{sim} - \bar{Q}_{sim})}} \right)^2$$

and

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

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

Percent bias (PBIAS) measures the average tendency of the simulated data to be either higher or lower than the observed data. A PBIAS value of 0 represents the ideal result, with lower values being preferred. Positive PBIAS values indicate model overestimation, while negative values suggest underestimation. The PBIAS is calculated using the following formula:

$$PIBS = 100 \times \frac{\Sigma(Q_{obs} - Q_{sim})}{\Sigma Q_{obs}}$$

RMSE is a widely used error index statistic. The equation below demonstrates how to calculate RSR, which is obtained by dividing the RMSE by the standard deviation of the observed data.

$$RSR = \frac{\Sigma(Q_{obs} - Q_{sim})^2}{\Sigma(\mathrm{Q_{obs}} - \bar{\mathrm{Q}}_{\mathrm{sim}})^2}$$

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.

3. Results and Discussion

3.1 Calibration and Validation Resultsof SWAT Model

3.1.1 Calibration

The purpose of SWAT model calibration is to provide a consistent method for selecting parameters for a specific catchment under given conditions. The primary goal was to determine the values that best aligned the simulated and observed stream flows during the calibration period. Two timeframes were selected for this process: 2003–2011 for calibration and 2012–2020 for validation. Fig. 5 below illustrates the calibration graph, comparing the observed discharge with the simulated discharge.

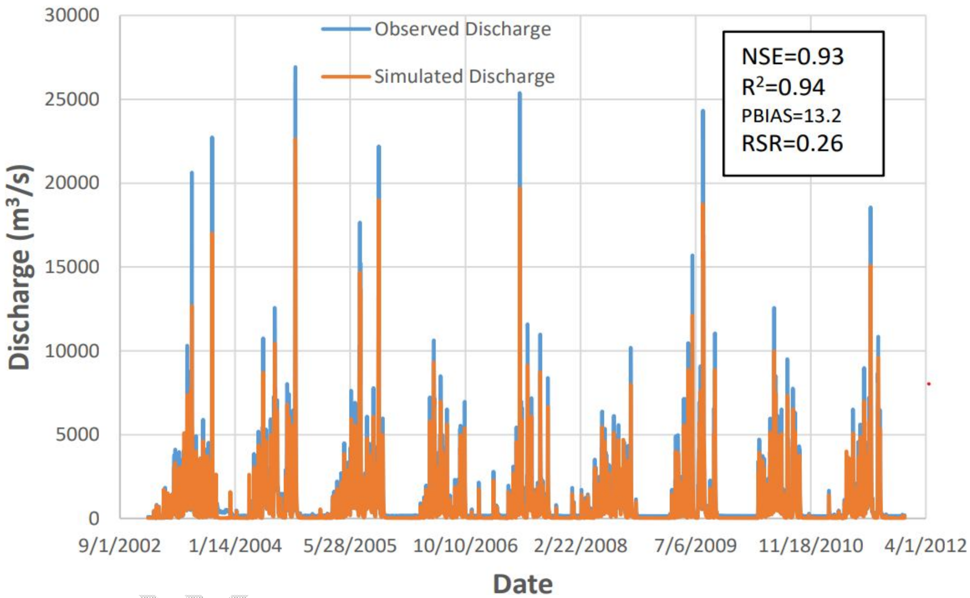

Fig. 5. Calibration of SWAT model in the time period 2003-2011

Based on the performance rating, with a coefficient of determination (R^2) of 0.94 (where $0 \leq R^2 \leq 1$), a Nash-Sutcliffe Efficiency index (NSE) of 0.93 (where $-\infty <$ NSE ≤ 1), a percent bias (PBIAS) of 13.2, and an RMSE observation standard deviation ratio (RSR) of 0.26, we can conclude that the calibration results are highly satisfactory in the time span 2003-2011 though most of the time simulated discharge is underestimated at the time of peak.

3.1.2 Validation

Validation period is selected for 2012-2021, calibrated model is run only one time using the calibrated parameters to check the performance of calibrated model. The validation graph along with observed discharge and simulated discharge are shown in following Fig. 6.

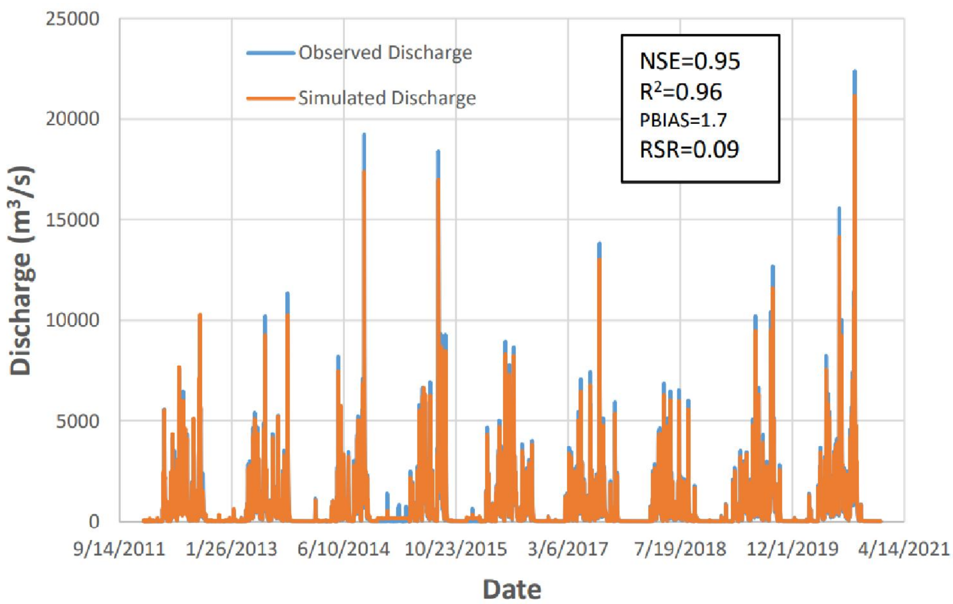

Fig. 6. Validation of SWAT model in the time period 2012-2021

The efficiency of SWAT model is evaluated by comparing the observed and simulated stream flow of the Teesta River at the Rangpur station during the validation period from 2012 to 2021. According to the figure, the validation result is considered acceptable, as the coefficient of determination (R^2) is 0.95 ($0 \leq R^2 \leq 1$), the Nash-Sutcliffe Efficiency index (NSE) is 0.96 ($-\infty <$ NSE ≤ 1), the RMSE-observations standard deviation ratio (RSR) is 0.09 and the percent bias (PBIAS) is 1.7. For the calibration period (2003–2011) the NSE and R^2valueswere0.93 and 0.94 respectively which were considered satisfactory. An NSE and R^2values greater than 0.75 is deemed acceptable for the SWAT model's calibration and validation period indicates satisfactory performance (Tables 3 and 4).

Table 3. Model performance metrics for calibration-validation time period

	NSE	R^2	RSR	PBIAS
Calibration (2003-2011)	0.93	0.94	0.26	13.2
Validation (2012-2022)	0.95	0.96	0.09	1.7

Table 4. General efficiency ratings of statistical test

Performance Rating	NSE	R^2	RSR	PBIAS
Very Good	0.75<NSE≤1	$0.75<R^2\leq1$	0.0<RSR≤0.5	PBIAS<±10
Good	0.65<NSE≤0.75	$0.65<R^2\leq0.75$	0.5<RSR≤0.6	±10<PBIAS<±15
Satisfactory	0.5<NSE≤0.65	$0.50<R^2\leq0.65$	0.6<RSR≤0.7	±15<PBIAS<±25
Unsatisfactory	NSE≤0.5	$R^2\leq0.50$	RSR>0.7	PBIAS>±25

The comparison Tables 3 and 4 reveals that the model performance metrics R^2, NSE, RSR, and PBIAS fall within acceptable ranges for both calibration and validation. The results of the model performance tests indicate that the output of model is excellent and reliable for use. Consequently, the calibration-validation results demonstrate that the model effectively simulates discharge data.

3.3. Impact of Land Use and Land Cover Change of the Teesta basin

The SWAT model, calibrated and validated for discharge, is used to measure the impacts of land use and land cover changes on sediment yield. To assess these effects, land use and land cover data for different types of land uses are applied as a land use input variable in the SWAT model, allowing for a comparison of the outputs based on the differences in land use and land cover. Real land use and land cover data are shown in Fig. 3 and Table 1. Now if the land use and land cover data are changed due to human and natural activities then the dependency of sediment on changes of different types of land use and land cover data sets are checked in the following sections.

3.3.1 Observation 1

If the land uses are changed and new land use become as bellow in Table 5 thenwe can see some changes in the values of land use data (Table 5) comparing with original land use in Table 1. In the changed land use scenario, the largest portion of land is covered by Evergreen Forest 41.31%, with Agricultural Land Generic coming next at 12.45%. Residential areas cover the smallest portion, accounting for only 0.18% of the land.The following Fig.7 shows the simulated sediment for two different types of land use which we have shown in Table 1 and 5. Here we can see that if we increased the Forest-Evergreen (from 28.64 % to 41.31 %) and Agricultural Land-Generic is decreased (from 25.12 % to 12.45 %) then sediment yield (SY) is decreased (Fig. 7). That is mean agricultural land and forest land has impact on sedimentation or soil erosion. Here agricultural land was decreased and forest land was increased that is why sediment yield is decreased (Fig. 7 and Table 6).

Table 5. Land-use of Teesta River Basin

Code	Label	Area (%)
AGRL	Agricultural Land Generic	12.45
AGR	Agricultural Land Row Crops	7.14
BARR	Barren	1.31
FRSE	Forest Evergreen	41.31
FRSD	Forest Deciduous	0.85
FRST	Forest Mixed	16.57
PAST	Pasture	0.86
RNGE	Range Grasses	11.87
RNGB	Range Brush	1.25
WATR	Water	6.17
WETF	Wetlands Forested	0.22
URBN	Residential	0.18

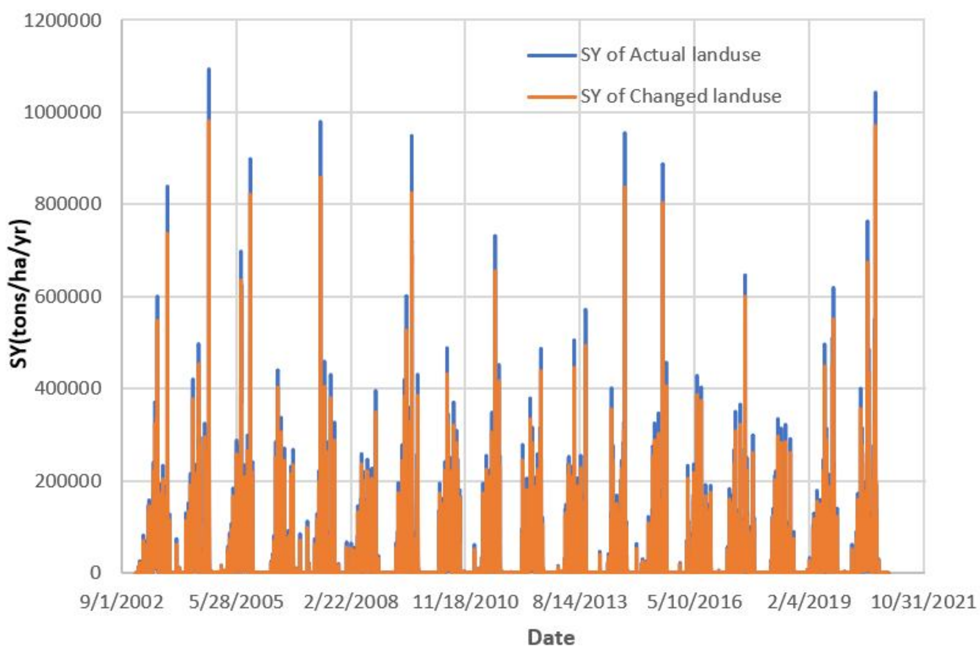

Fig. 7: Simulated sediment for two different types of land use

Table 6. Simulated sediment yield for different land use and land covers

Component	SY of Actual land used	SY of Observation 1	Change(%)
Average SY(tons/ha/yr)	30835.36	30790.53	-0.15%

3.3.2 Observation 2

Consider the original land use and land cover data are changed as shown in Table 7 where the largest portion of land is covered by Agricultural Land-Generic (56.43%) followed by Range-Grasses coming next at 11.69 % and Water is 11.61 %. Forest-Mixed cover the smallest portion, accounting for only 0.18% of the land. Agricultural Land is increased (from 25.12 % to 56.43 %) whereas Forest-Evergreen is decreased (28.64 % to 3.51%). Fig. 8 shows the SY is decreased where blue color graph indicates SY for original land use and orange one shows SY for changed land use and land cover (Table 8).

Table 7. Land-use of Teesta River Basin

Code	Label	Area (%)
AGRL	Agricultural Land Generic	56.43
AGRR	Agricultural Land Row Crops	7.14
BARR	Barren	1.31
FRSE	Forest Evergreen	3.51
FRSD	Forest Deciduous	0.85
FRST	Forest Mixed	0.18
PAST	Pasture	0.22
RNGE	Range Grasses	11.69
RNGB	Range Brush	1.25
WATR	Water	11.61
WETF	Wetlands Forested	4.96
URBN	Residential	0.86

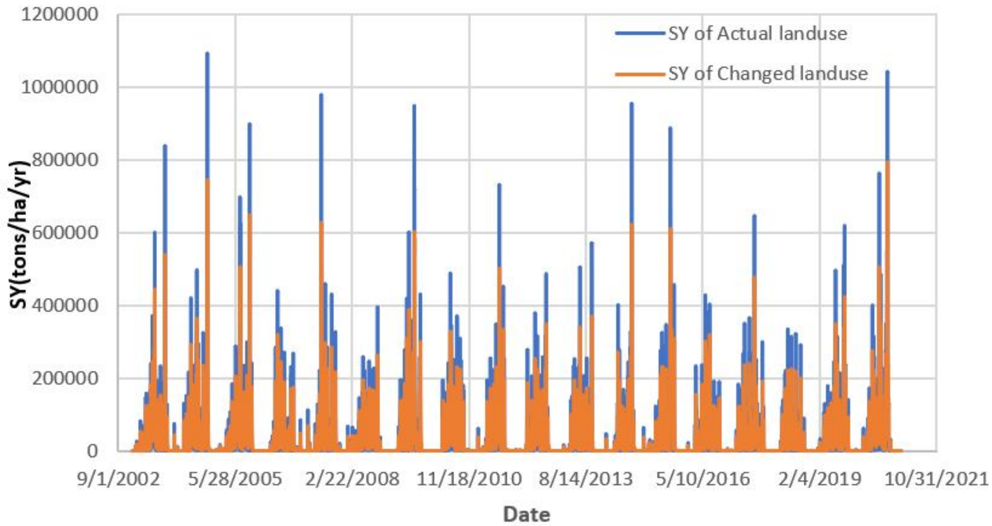

Fig. 8. Simulated sediment for two different types of land use

Table 8. Simulated sediment yield for different land use and land covers

Component	SY of Actual land used	SY of Observation 2	Change(%)
Average SY(tons/ha/yr)	30790.53	30257.79	-1.73%

3.3.3 Observation 3

In the bellow Table 9 we see some changes in the values (comparing with Table 1). The largest portion of land is covered with Agricultural Land Generic coming at 28.12%, second highest portion of land is covered by Forest-Evergreen (25.12 %) and 12.27 % land covered by Wetlands-Forested. If we compare Table 9 and Table 1 we can see residential land is increased from 0.18 % to 10.48 %, Agricultural Land-Row Crops is decreased (from 7.14 % to 0.85), Barren is increased from (1.31 % to 11.69 %), Wetlands-Forested is increased (from 0.23 % to 12.27 %). Fig. 9 shows SY is increased due to increased residential land use, its mean residential land use has great impact on SY (Table 10).

Table 9. Land-use of Teesta River Basin

Code	Label	Area (%)
AGRL	Agricultural Land Generic	28.12
AGR	Agricultural Land Row Crops	0.85
BARR	Barren	11.69
FRSE	Forest Evergreen	25.12
FRSD	Forest Deciduous	7.14
FRST	Forest Mixed	0.18
PAST	Pasture	1.25
RNGE	Range Grasses	1.31
RNGB	Range Brush	0.86
WATR	Water	0.23
WETF	Wetlands Forested	12.27
URBN	Residential	10.48

Table 10. Simulated sediment yield for different land use and land covers

Component	SY of Actual land used	SY of Observation 3	Change(%)
Average SY(tons/ha/yr)	30790.53	31058.96	+0.86%

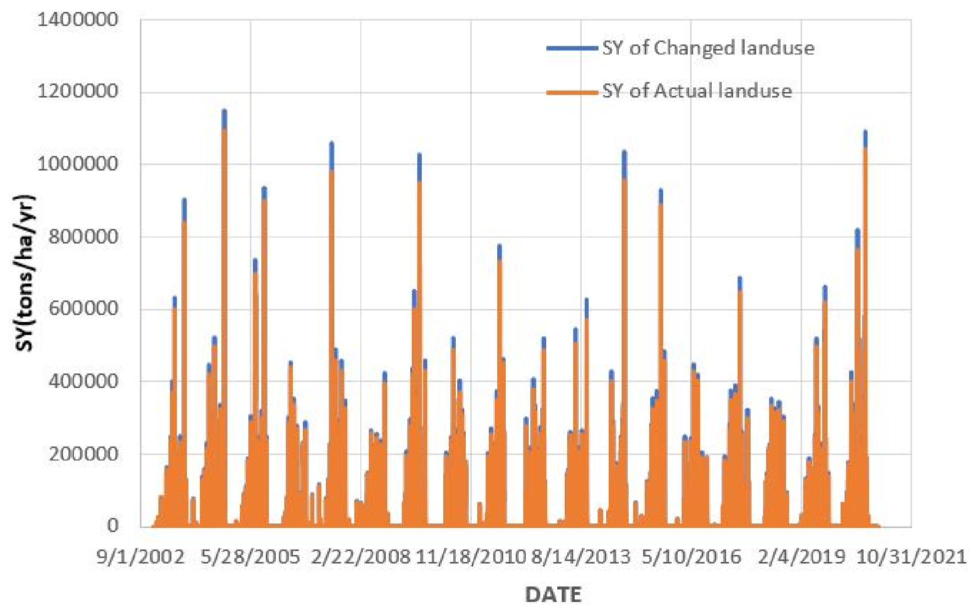

Fig. 9. Simulated sediment for two different types of land use

3.3.4 Observation 4

Consider the existing land use and land cover is changed and new land use and land cover become as in Table 11;we see some changes in the values (comparing with Table 1). The largest portion of land is covered by Evergreen Forest (28.64%), with Deciduous forest coming next at 25.12%. Forest mixed cover the smallest portion, accounting for only 0.18% of the land. Here significant changed is occurred at agricultural land decreased (25.12 % to 0.85 %) and residential land is increased (0.18 % to 17.23 %). The following Fig. 10 shows the simulated sediment for two different types of land use which we have shown in Table 1 and 11.Fig. 10 and Table 12 ilustrateSY is slightly decreaseddue to decreased around 24 % of agricultural land and increased around 17 % of residential land.

Table 11. Land-use of Teesta River Basin

Code	Label	Area (%)
AGRL	Agricultural Land Generic	0.85
AGR	Agricultural Land Row Crops	7.14
BARR	Barren	11.69
FRSE	Forest Evergreen	28.64
FRSD	Forest Deciduous	25.12
FRST	Forest Mixed	0.18
PAST	Pasture	1.25
RNGE	Range Grasses	1.31
RNGB	Range Brush	0.86
WATR	Water	0.22
WETF	Wetlands Forested	5.52
URBN	Residential	17.23

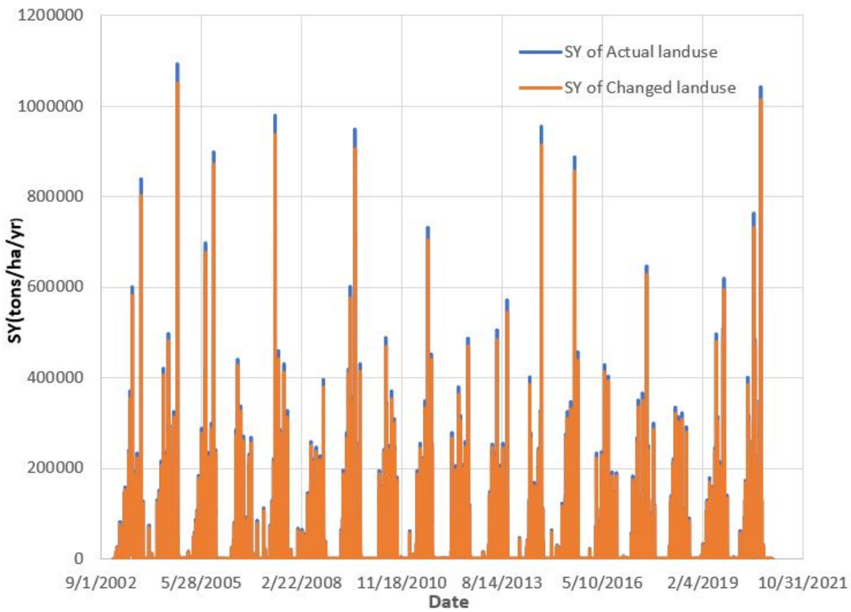

Fig. 10. Simulated sediment for two different types of land use

Table 12. Simulated sediment yield for different land use and land covers

Component	**SY of actual land used**	**SY of Observation 4**	**Change(%)**
Average SY(tons/ha/yr)	30790.53	30377.02	-1.34%

3.3.5 Observation 5

Changed land use and land cover in Table 13 has the largest value of Agricultural Land-Generic which is 28.64% and next portion is forest-deciduous 25.12 % followed by residential land 17.23 %, least portion is Mixed Forest with 0.18. Here noticeable changed is happened in barren land use (increased 1.13 % to 11.87 %),residential land (increased from 0.18 % to 17.23 %), forest-mixed (decreased 10.48 % to 0.18 %), forest-deciduous (increased 0.85 % to 25.12 %). The following figure shows the sediment yield is increased slightly due to increase of residential and barren land use (Fig. 11 and Table 14).Here increase of residential and barren land and decrease of different types of Forest land minimize or share their efect on sediment yield, so not so cahnge in noticed (Fig. 11 and Table 14). This change is attributed to the minor land cover changes in the catchment, emphasizing the impact of land use and cover changes on the area's hydrology.

Table 13. Land-use of Teesta River Basin

Code	**Label**	**Area (%)**
AGRL	Agricultural Land Generic	28.64
AGR	Agricultural Land Row Crops	7.14
BARR	Barren	11.87
FRSE	Forest Evergreen	0.85
FRSD	Forest Deciduous	25.12
FRST	Forest Mixed	0.18
PAST	Pasture	1.25
RNGE	Range Grasses	1.31
RNGB	Range Brush	0.86
WATR	Water	0.22
WETF	Wetlands Forested	5.52
URBN	Residential	17.23

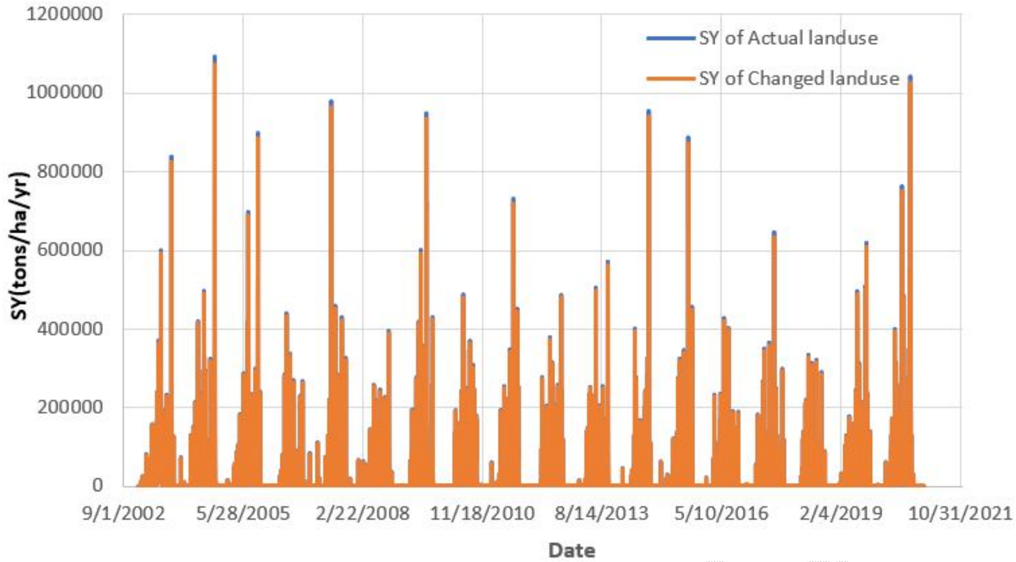

Fig.11. Simulated sediment for two different types of land use

Table 14. Simulated sediment yield for different land use and land covers

Component	SY of actual land used	SY of Observation 5	Change(%)
Average SY(tons/ha/yr)	30790.53	31020.23	+0.75%

4. Conclusions

SWAT model is used to estimate the discharge and measure the effects of land use and land cover changes on sedimentation of the Teesta Watershed. The SWAT model effectively simulated streamflow, yielding satisfactory statistical results. The calibrated model showed the strong agreement between observed and simulated discharge. Additionally, the average sediment yield of the catchment is estimated for different types of land use scenarios where we can see the estimation of sediment yield depend on uses of land for different purposes.Sediment yield is increased due to increase of residential land decreased due to increase of forest land. The results illustrated that, a properly calibrated SWAT model may produce accurate hydrologic simulation results in connection to land use if all uncertainties are reduced, which can be useful to estimate water and environmental resources changes in advance and will help policy and decision makers for sustainable development. Calibrated SWAT model can be used to predict the discharge when observe discharge data is unavailable or impossible to measure due to different constraints and to help policy maker to maintain appropriate ratio of land use and land cover for sustainable development avoiding soil erosion.

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