IMPACT OF LANDUSE LAND COVER CHANGE ON STREAMFLOW OF UPPER BAITARANI RIVER BASIN USING SWAT

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Abstract Change in land use and land cover pattern influences the hydrology of a watershed by changing its stream flow and groundwater characteristics. The main objective of this study was to assess the land use land cover change impact on stream flow of Upper Baitarani River Basin using SWAT (Soil & Water Assessment Tool). SWAT is a helpful tool to determine the different hydrologic characteristics under varying conditions. In this work, SWAT model was integrated with ArcGIS. The study area was delineated based on Anandpur Hydrological Observation Station and a hydrologic model was set up using SWAT software. The model was run individually using 1995 and 2013 land use in daily time step for the period 1979-2013 with a warm-up period of five years. Calibration and validation of both models were done using global sensitivity approach of Sequential Uncertainty Fitting (SUFI2) algorithm in SWAT Calibration and Uncertainty Procedure (SWAT-CUP) software. The results showed both models worked satisfactorily. In Upper Baitarani river basin built-up area has increased significantly whereas forest cover and agricultural area have decreased in the time period of 18 years (1995-2013). As an effect of this land use, land cover change the mean annual streamflow has increased 3.78%. The results have proven due to land use land cover change, stream flow can change and SWAT can efficiently assess that change.

Keywords LUCC pattern, SWAT modeling, SWAT-CUP, SUFI2 algorithm.

1. Introduction

Land use cover change (LUCC) results in an adverse impact on the environment (Ndulue et al., 2015) as well as streams within a basin. The river regime changes due to the temporal variation of runoff distribution (Kashaigili et al., 2008). In developing countries like India, agriculture is the primary sector for economic progress (Himani, 2014). Parallel with this rapid growth of population (Kulkarni et al., 2014) can be observed. To prepare land for agriculture and residence the existing land cover has to be processed. As a result, the land changes its characteristics which influence the hydrological response of watershed (Welde et al., 2017).

The Upper Baitarani basin which is one of the most important water contributors in Odisha state has undergone a lot of transformations of LUCC (Uniyal et al., 2015). SWAT (Soil & Water Assessment Tool) is a river basin scale model that works on a daily time interval. It useful tool for hydrologic modeling as long-term hydrological responses can be quantified through SWAT in very less time. SWAT Model components include weather, hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, agricultural management, stream routing and pond/reservoir routing for proper watershed modeling (Arnold et al.,2005). The main objective of present study was to assess the impact of this land use cover change on streamflow for the period 1995 to 2013 using SWAT.

2. Materials and methods

2.1 STUDY AREA

The study was conducted for Baitarani Basin. Originating from the Guptaganga hill of Keonjhar District of Odisha at an elevation about 900 m above Mean Sea Level the Baitarani River crosses a length of 360 km and meets with the Bay of Bengal. The Brahmani River flows on the South and West of the basin, the Subarnarekha River on the North and the Budhaganbalanga and the Bay of Bengal on the east. About 6.7% and 93.3% area of Baitarani basin falls in Jharkhand and Odisha respectively with a total catchment area of 10,982 sq. km.

The upper reach of Baitarani River is up to Anandpur hilly region. The study area lies approximately between east longitudes 85°10' to 86°23' and north latitudes 20°53' to 22°15' covers area about 8,619 sq.km. Anandpur is situated at Keonjhar district of Odisha (Figure1). The climate is Tropical with average annual rainfall of 1442.53 mm. The hilly areas face lesser temperature variations compare to plain areas during the years. Generally, December and early January are the coldest months with a minimum temperature of 12° C whereas the average annual maximum temperature of 37.67° C and the annual minimum temperature is 20.32° C. April and May are the hottest months of the year when the temperature varies between 35° C to 38°C. The wind velocity is higher in months of April, May, and June whereas it's lesser in December and January (CWC, 2014).The basin contains loam soil, sandy soil, and sandy clay loam soil. Forest, agriculture and built-up area cover the major part of the basin.

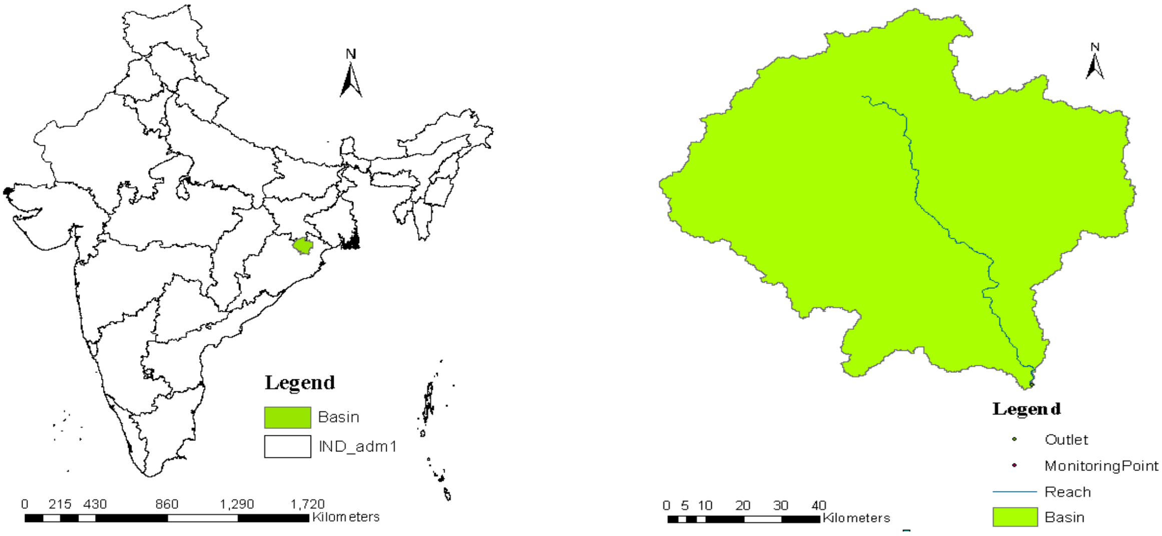

Figure1. Location of study area

2.2 INPUT DATA

2.2.1 Meteorological data

As meteorological parameters (precipitation, maximum and minimum temperature, relative humidity, solar radiation, wind speed etc.) influence the hydrologic cycle greatly. That's why to create SWAT model this data is very compulsory. The meteorological data from 1979 to 2013 was obtained from The National Centers for Environmental Prediction (NCEP) (https://globalweather.tamu.edu). The data was collected from six stations inside the study area.

2.2.2 GIS data

Terrain data. As water flows from high elevation to low elevation terrain data is necessary for hydrological modeling. The DEM (Digital Elevation Model) of Baitarani river basin was obtained in the form tiles from CIGAR-CSI website (http://srtm.csi.cgiar.org) with 90 by 90 m DEM resolution. These tiles were mosaiced into a single tile in ArcGIS 10.1. The study area was automatically delineated with the help of the outlet point (Figure2). DEM was also used to depict the drainage pattern, flow accumulation, and streamflow networks of the basin area.

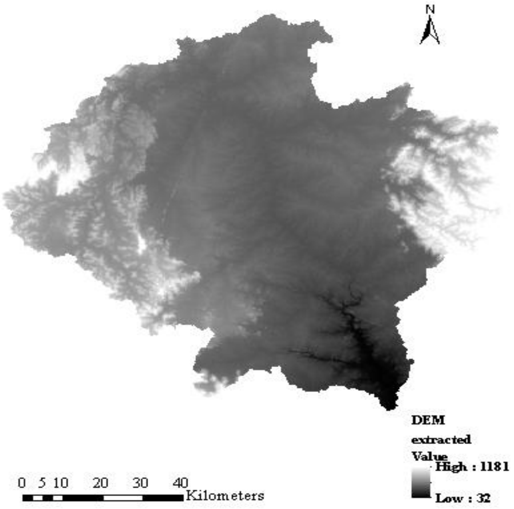

Figure2. Digital Elevation Model of Upper Baitarani Basin

Soil Data. The soil texture plays a very important role in SWAT model as different kind soils in the world have different physical and chemical characteristics.Harmonized world soil data of 1:50,00,000 scale in vector format was acquired from FAO (Food and Agricultural Organisation) soil portal (http://www.fao.org). The soil map of the study area was clipped by the shapefile in ArcGIS 10.1. With the help of Harmonized world soil database, the type of soil in the study area was obtained. From this study, it was observed (Figure3)the Upper Baitarani river basin contains I-Ne or loam soil (28.38%), I-bc or loam soil (6.65%), Nd50-2b or a sandy clay loam (64.92%) and Lf95-1a or sandy loam soil (0.05%).

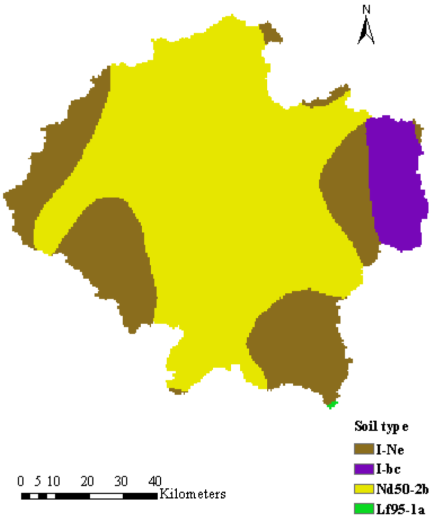

Figure3. Soil map of Upper Baitarani Basin

Land use land cover data. Land use is defined as the expenditure of land to produce goods and services. Hence, land use is dependent on the purpose for which the land is being used whereas Land cover means natural physical cover, as seen by eyes or remote sensing (Ndulue et al., 2015).Land use land cover maps were obtained from USGS LANDSAT satellite imagery (https://earthexplorer.usgs.gov/). Using path 139 and 140 and row 45 LANDSAT 5 and 8 satellite images for 1995 and 2013 (spatial resolution 30 m) were attained in the form of a tile. Then in ArcGIS 10.1, the tiles of both years were mosaiced individually. Using the shapefile of the study area the mosaiced images were clipped separately. Each clipped image was classified into five categories of land use-cover with the help of maximum likelihood algorithm in supervised classification tool of ArcGIS (Figure4, 5). The five classes were water body, forest, agriculture, barren land and built up area. Table.1 represents the quantified change of land use-cover categories.

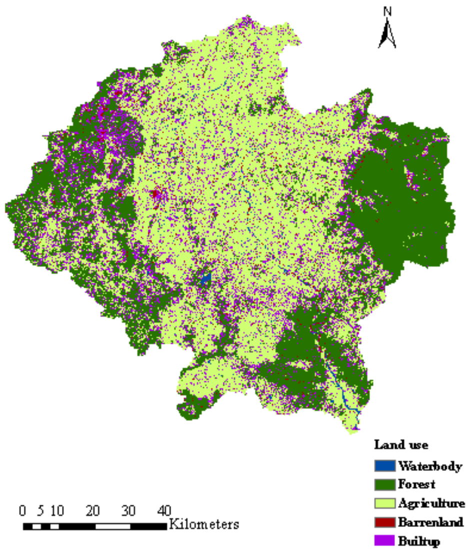

Figure4. Landuse land cover map (1995)

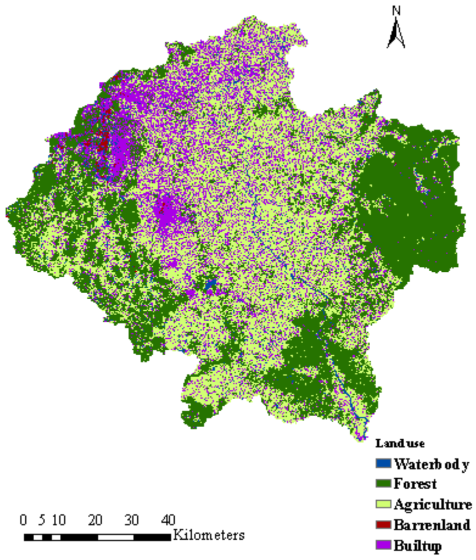

Figure5. Landuse land cover map (2013)

Table 1: Different land use land cover area in Upper Baitarani basin

ID	LANDCOVER SPECIFICATION	1995		2013		CHANGE
		AREA(KM^2)	%	AREA(KM^2)	%	%
1	**WATER**	**82.74**	**0.96**	**93.95**	**1.09**	**+0.13**
2	**FOREST**	**2,773.59**	**32.18**	**2,722.74**	**31.59**	**-0.59**
3	**AGRICULTURE**	**4,274.16**	**49.59**	**3,741.51**	**43.41**	**-6.18**
4	**BARREN LAND**	**178.42**	**2.07**	**38.79**	**0.45**	**-1.62**
5	**BUILT UP**	**1310.09**	**15.20**	**2,022.01**	**23.46**	**+8.26**
	TOTAL AREA	**8,619**	**100**	**8,619**	**100**	

2.2.3 Hydrological data

Daily discharge data (1979-2013) of Baitarani River at Anandpur stream gauge station (21°12'40"N, 86°7'14"E) was obtained from Water Resources Information System of India (http://india-wris.nrsc.gov.in/wris.html). This data was further used for calibration and validation purposes of the SWAT model.

2.3 SWAT MODEL SET UP AND SIMULATION

SWAT is a comprehensive, Semi distributed, hydrologic model which runs at a continuous time-step (Arnold et al., 2012). It was developed by Dr. Jeff Arnold for USDA-ARS to determine the impact of land management practices on water as well as sediment, agricultural yields in different complex watersheds under varying land use and soil conditions (Neitsch et al., 2009).SWAT uses spatial and temporal data as input. Spatial data includes DEM (Digital Elevation Model), land-use map and soil map. Temporal data includes hydrological data (stream flow) and weather data (precipitation, temperature, wind speed, relative humidity and solar radiation). SWAT divides a basin into multiple sub-basins depending on the topographic criteria and further subdivided into a number of HRUs (Hydrologic Response Units) on the basis of homogeneous land use, soil and slope combination characteristics. Simulation can be done for different kinds of hydrological (runoff, water quality, evapotranspiration etc.), agricultural variables (crop yield, nutrients etc.). Based on the requirement and available data user can easily simulate the variables in SWAT.

Hydrological simulation of the basin was carried out using ArcGIS extension of SWAT called ArcSWAT (Arnold et al., 2013). The SWAT model was developed and refined by the water balance equation (1)

$$SW_t = SW_o + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \qquad (1)$$

SW_t =Final soil water content in mm, SW_o=Initial soil water content on day i (mm), R_{day}=Amount of precipitation on day i (mm), Q_{surf}=Amount of surface runoff on day i (mm), E_a =Amount of evapotranspiration on day i (mm), W_{seep}= Amount of water entering the vadose zone from soil profile on day i (mm), Q_{gw}= Amount of return flow on day i (mm)

In this study, ArcSWAT v2012.10.1.18 (http://swat.tamu.edu/software/arcswat) was used. To set up the SWAT model the study area was automatically delineated with the help of the outlet at Anandpur stream gauge station (21°12'40"N, 86°7'14"E) (CWC, 2014). The Upper Baitarani basin had produced only one sub-basin and that was further subdivided into 18 HRUs based on inputted soil and land use/cover data. Then the model was simulated from 1979 to 2013 on daily time step with a warm-up period of five years. The flowchart of complete methodology has been shown in Figure6.

2.4 SENSITIVITY ANALYSIS, CALIBRATION AND VALIDATION OF SWAT MODEL

2.4.1. Sensitivity analysis

Sensitivity analysis identifies the main parameters which effect the SWAT output flow using global sensitivity approach of Sequential Uncertainty Fitting (SUFI2) algorithm in SWAT-CUP (Calibration and Uncertainty Procedure) (Abbaspour,2007). Here, in this work, fourteen parameters were taken initially to examine their sensitiveness. The range of these parameters was set from SWAT-CUP user manual. After an initial iteration run, Global sensitivity approach checked the sensitivity of one parameter relative to another and arrange the parameters by ranks according to their t-stat and p-values. The allowable ranges and the best-fitted values were obtained by sensitivity analysis. In this study, fourteen stream flow influencing parameters were tested for sensitivity (Table 2).

2.4.2. Calibration and validation of swat model

From the graphical comparison, it was understood that the SWAT model has overestimated the discharge for both 1995 and 2013 land use scenarios. That’s why it was necessary to perform proper calibration and validation of the model before carrying out any further analysis using the model. Only selected sensitive parameters were used for calibration and validation process. For 1995 land use scenario the model was calibrated for the period of 1986-1992 and validated for the period of 1993-1995. Similarly, 2013 land use scenario model was calibrated for the period of 2004-2010 and validated for the period of 2011-2013.To evaluate the model performance, four statistical standards, Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R^2) and the percent bias (PBIAS) were used. (Moriasi, 2007).

$$NSE = 1 - \frac{\sum_{i=1}^{n} (O_i - S_i)^2}{\sum_{i=1}^{n} (O_i - O)^2}$$

$$PBIAS = \frac{\sum_{i=1}^{n} (O_i - S_i) * 100}{\sum_{i=1}^{n} (O_i)}$$

$$RSR = \frac{\sqrt{\sum_{I=1}^{n} (\mathrm{Oi} - \mathrm{Si})^2}}{\sqrt{\sum_{I=1}^{n} (\mathrm{Oi} - \mathrm{O})^2}}$$

$$R^2 = \frac{[\sum_{i=1}^{n}(O_i - O)(S_i - S)]^2}{\sum_{i=1}^{n}(O_i - O)^2 * \sum_{i=1}^{n}(S_i - S)^2}$$

Where O_i is the observed daily discharge, S_i is the simulated daily discharge, O is the average measured discharge, S is the average simulated discharge, n is the number of observations.

NSE describes the prediction ability of hydrological model by comparing the simulated output to the observed data. It ranges from $-\infty$ to 1. NSE value close to 1, indicates the model is accurate.

PBIAS incorporates the model average tendency of simulation compare to the observed data. PBIAS greater than 0, represents model has underestimated the output whereas lesser than 0 indicates model has overestimated the output. The ideal value of PBIAS is 0. (Moriasi, 2007).

R^2 is used to understand how well-observed output is replicated by the model, on the basis of the proportion of total variance of the simulated output data. The range of R^2 from 0 to 1. An R^2 value close to 1 specifies the model is precise.

RSR is the ratio of the root mean square error to the standard deviation of measured data. It standardizes RMSE (root-mean-square error) using the observation standard deviation. RSR varies from 0 to large positive values. The lower value of RSR indicates better the model fit.

A model simulation can be accepted satisfactory if NSE is greater than o.4, PBIAS is ± 25% and R2 is greater than 0.5 for streamflow (Ajai et al., 2014).

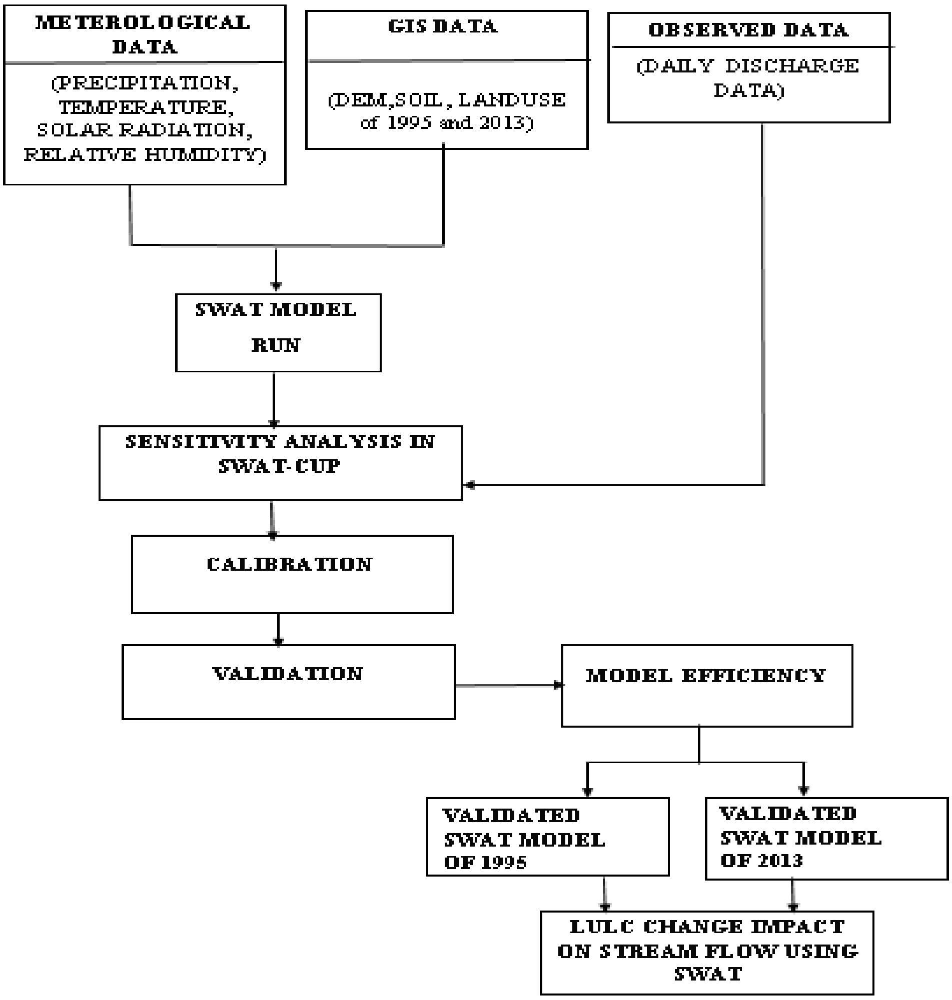

Figure6. Flowchart of methodology

3. Results and Discussion

3.1 SENSITIVITY ANALYSIS OF STREAMFLOW RESULTS

Global sensitivity analysis showed out of 14 parameters (Table 2) only six parameters were very sensitive to stream flow. The sensitive parameters are presented according to their sensitiveness (Table 2) for 1995 land use (LU) scenario model. The sensitivity analysis indicates the most sensitive parameter for the stream flow was Base-flow alpha factor for bank storage (ALPHA_BNK). The other parameters which were sensitive were SCS runoff curve number (CN2), available water capacity of the soil layer (SOL_AWC), Effective hydraulic conductivity in main channel alluvium (CH_K2), Saturated hydraulic conductivity (SOL_K), Soil evaporation compensation factor (ESCO). Rest eight parameters were found not sensitive to streamflow in the catchment as their p-values were greater than 5% (Anaba et al., 2017). The best-fitted values and ranges obtained after sensitivity analysis of these six most sensitive parameters are presented in Table 3.

Table 2: Sensitivity Analysis of streamflow parameters for 1995 scenario model

SL. No.	Parameter name	t-stat	p-value
1	ALPHA_BNK (Base-flow alpha factor for bank storage)	14.535	0.000
2	CN2 (SCS runoff curve number)	10.966	0.000
3	SOL_AWC (Available water capacity of the soil layer)	-4.673	0.000
4	CH_K2 (Effective hydraulic conductivity in main channel alluvium)	-3.086	0.002
5	SOL_K (Saturated hydraulic conductivity)	3.020	0.002
6	ESCO (Soil evaporation compensation factor)	-2.035	0.042
7	SLSUBBSN (Average slope length)	1.668	0.095
8	GW_REVAP (Groundwater “revap” coefficient)	-1.556	0.120
9	CH_N2 (Manning’s “n” value for the main channel)	-1.301	0.193
10	REVAPMN (Threshold depth of water for revap or percolation to occur)	-1.129	0.259
11	GWQMN (Threshold depth of water in the shallow aquifer required for return flow to occur)	0.983	0.326
12	HRU_SLP (Average slope steepness)	0.816	0.414
13	ALPHA_BF (Base-flow alpha factor)	0.707	0.479
14	GW_DELAY (Groundwater delay)	0.397	0.691

Table 3: Ranges and best-fitted values of flow calibration parameters

SL. No.	Parameter name	Fitted value	Minimum value	Maximum value
1	v_ALPHA_BNK.rte	0.949	0.000	1.000
2	r_CN2.mgt	0.150	-0.200	0.200
3	r_SOL_AWC.sol	0.063	-0.200	0.400
4	v_CH_K2.rte	117.625	5.000	130.000
5	r_SOL_K.sol	-0.782	-0.800	0.800
6	v_ESCO.hru	0.875	0.800	1.000

In the second case in which the 2013 land use scenario model was used results showed out of fourteen parameters (Table 4), only five parameters were very sensitive to stream flow. Those fourteen parameters are presented according to their sensitiveness measured by p-value and t-stat value (Table 4). The sensitivity analysis indicates, in this case, the most sensitive parameter for the stream flow was Effective hydraulic conductivity in main channel alluvium (CH_K2). The other parameters which were sensitive were SCS runoff curve number (CN2), Base-flow alpha factor for bank storage (ALPHA_BNK), Saturated hydraulic conductivity (SOL_K), Groundwater revap coefficient (GW_REVAP).Rest eight parameters were found not sensitive to streamflow in the catchment as their p-values were greater than 5% (Anaba et al., 2017). The best-fitted values and ranges of these five most sensitive parameters are presented in Table 5.

Table 4: Sensitivity Analysis of streamflow parameters for 2013 scenario model

SL. No.	Parameter name	t-stat	p-value
1	CH_K2 (Effective hydraulic conductivity in main channel alluvium)	9.319	0.000
2	CN2 (SCS runoff curve number)	6.321	0.000
3	ALPHA_BNK (Base-flow alpha factor for bank storage)	5.866	0.000
4	SOL_K (Saturated hydraulic conductivity)	3.320	0.000
5	GW_REVAP (Groundwater “revap” coefficient)	-2.022	0.044
6	REVAPMN (Threshold depth of water for revap or percolation to occur)	1.877	0.061
7	GWQMN (Threshold depth of water in the shallow aquifer required for return flow to occur)	-1.583	0.114
8	HRU_SLP (Average slope steepness)	1.347	0.179
9	CH_N2 (Manning’s “n” value for the main channel)	1.273	0.204
10	SOL_AWC (Available water capacity of the soil layer)	0.963	0.334
11	ESCO (Soil evaporation compensation factor)	-0.912	0.362
12	ALPHA_BF (Base-flow alpha factor)	0.654	0.514
13	GW_DELAY (Groundwater delay)	0.508	0.612
14	SLSUBBSN (Average slope length)	-0.491	0.624

Table 5: Ranges and best-fitted values of flow calibration parameters

Rank	Parameter name	Fitted value	Minimum value	Maximum value
1	v_GW_DELAY.gw	171.539	30.000	450.000
2	r_CN2.mgt	0.070	-0.200	0.200
3	r_SOL_K.sol	0.097	-0.800	0.800
4	v_ALPHA_BF.gw	0.463	0.000	1.000
5	v_GW_REVAP.gw	0.016	0.000	0.200

The extension (e.g.-.mgt, .rte) refers to the SWAT input text file where the parameters are selected. The qualifier r_- refers to the relative change in the parameter where the value from the SWAT database is multiplied by 1 plus a factor in the given range. v_-refers to the substitution of a parameter by a value from the given range.

3.2 SWAT MODEL CALIBRATION AND VALIDATION RESULT

The Graphical representation of streamflow indicates the calibrated (Figure7 (a)) and validated (Figure7 (b)) results for1995 LU model. It also depicts the calibration results showed a good match compare to the validated stream flow results. Besides that, the statistical objective functions in SWAT-CUP evaluated the model performance was good (Moriasi et al., 2007).

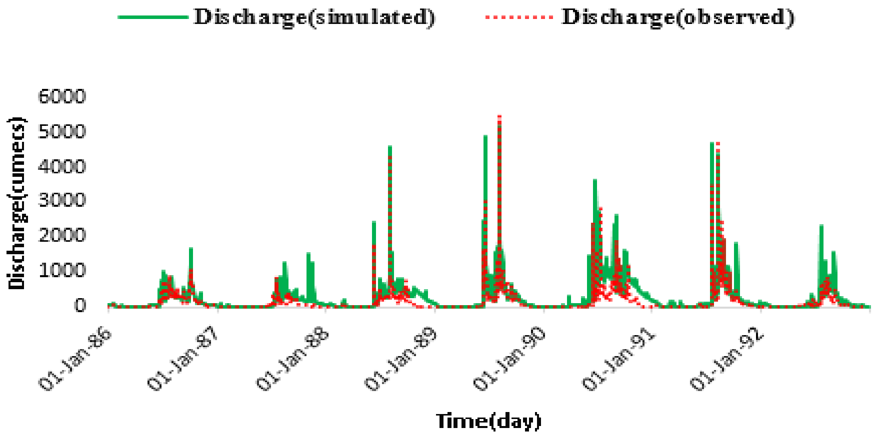

Figure7(a). Observed and simulated daily discharge during calibration period (1986-1992) for 1995 LU model

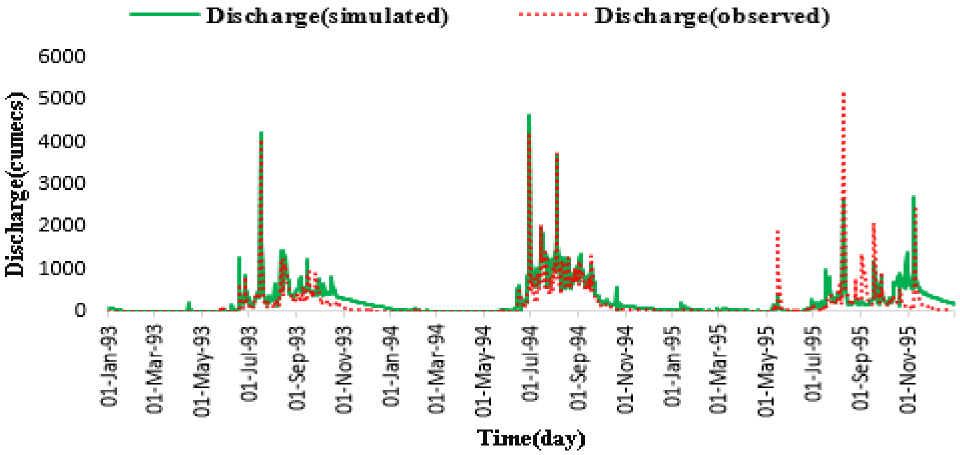

Figure7(b). Observed and simulated daily discharge during validation period (1993-1995) for 1995 LU model

Table 6: SWAT model calibration and validation statistical objective function for1995 LU model

Stage of model	Statistical parameters			
	R^2	NSE	RSR	PBIAS
calibration (1986-1992)	0.700	0.661	0.512	-15.0
validation (1993-1995)	0.677	0.623	0.551	-17.0

Again for 2013 LU model after the calibration (Figure8 (a)) and validation (Figure8 (b)), the graphical and objective functions indicated the 2013 LU model was also good.

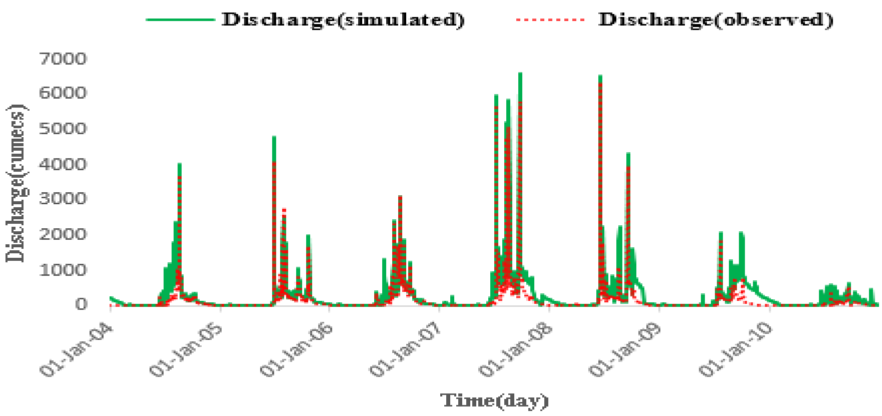

Figure8(a). Observed and simulated daily discharge during calibration period (2004-2010) for 2013 LU model

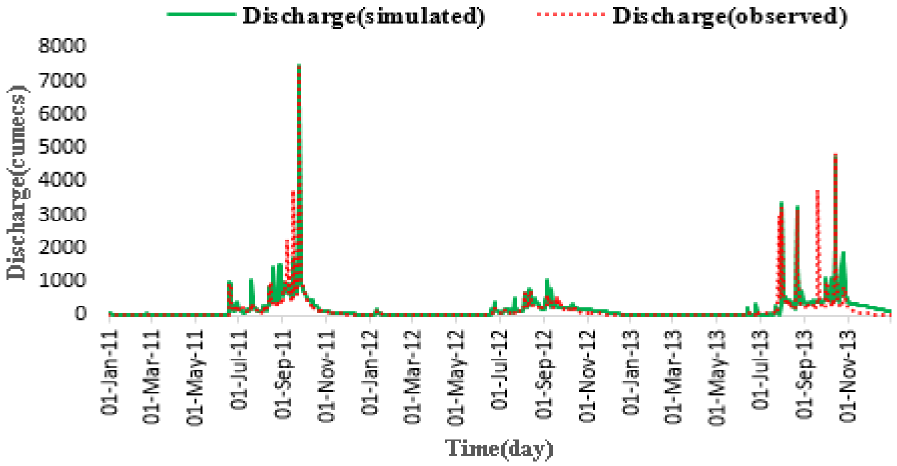

Figure8(b). Observed and simulated daily discharge during calibration period (2011-2013) for 2013 LU model

Table 7: SWAT model calibration and validation statistical objective function for2013 LU model

Stage of model	Statistical parameters			
	R^2	NSE	RSR	PBIAS
calibration (2004-2010)	0.685	0.621	0.560	-14.0
validation (2011-2013)	0.637	0.611	0.574	-17.0

3.3 MODELLING STREAM FLOW RESPONSE TO LAND USE DYNAMICS

3.3.1. Establishing scenarios to assess impacts of land-use

Different scenarios were established to assess the impact of land use change on streamflow by SWAT 2012. The one factor at a time approach (Li et al., 2009) was taken into account. In this approach, one factor at each time had to be changed while the others had to keep constant to analyze the effect of land use on stream flow.

Scenario I: Climate of 2008-2013 and land use of 2013

Scenario II: Climate of 2008-2013 and land use of 1995

Comparing the average annual discharge due to 1995 land use and 2013 land use, it can be seen that only due to land use change streamflow has increased 3.78% (Table8).

Table 8: Streamflow response to land use change

Scenario	Mean annual streamflow (m^3/s)
I	229.69
II	221.33
Change(I-II) with respect to scenario II	+3.78%

4. Conclusion

The study showed the Upper Baitarani river basin has undergone a significant change in eighteen years(1995-2013).Forest cover, agriculture, and barren land have decreased significantly whereas built-up area has increased due to urbanization.In this study, the SWAT model was utilized to assess the impact of land-use landcover change on streamflow in Upper Baitarani basin. After calibration and validation, the objective functions indicated both the SWAT models have simulated the streamflow satisfactorily. This indicates, SWAT model can predict the streamflow for the present as well as future scenarios, which can be reliable for Upper Baitarani basin.Using two land-use of 1995 and 2013 under a constant climate, it was clear that only due to land-use change annual average streamflow has increased 3.78%. From this study it can be concluded there is a direct relationship between land use land cover and streamflow as a change in land use can change the streamflow pattern.That's why for effective watershed management the streamflow should be continuously assessed.

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