Impact of land use-land cover changes on the stream flow of the Kolab River Basin using SWAT model

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Abstract: Hydrological parameters are affected by many factors, including long-term effects such as climate change that alter rainfall-runoff relationships, and short-term effects related to human intervention (e.g., dam construction, land-use and land-cover change (LUCC)). The consequential impacts of human-induced climate changes and land use changes on hydrological parameters have become a big challenge and convinced to give great attention of many researchers. The Kolab river watershed, Odisha is an important watershed supporting drinking water and recreational activities. In this paper, it is assessed the long-term impacts of LU-LC changes on hydrological parameters using the Soil and Water Assessment Tool (SWAT) and a detailed LULC record from 1995-2013.

Keywords: Arc GIS, LUCC pattern, SWAT modelling, SWAT-CUP, SUFI2 algorithm

1. Introduction:

Land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other. Human activities and few natural processes are the principal influences of land use-land cover changes. As agriculture is the prime sector of India's economic system and the population of this country is growing up abruptly, the existing land cover has to be processed. Land use-land cover changes are the one of predominant influences on hydrological parameters and soil erosion including climate change.

Many studies have taken into consideration the impact of land use-land cover changes on stream flow (Bernt Matheussen, Robin L.Kirschbaum.2000, R.T.W.L. Hurkmans, W. Terink.2009). Few studies have carried out to investigate the impact of land use-land cover changes due to urbanization on surface microclimate and hydrology: a satellite perspective (Toby N Carlson, S Traci Arthur.2000). Though lot of hydrological models are available, like Water Erosion Prediction Project (WEPP), Hydrologic Simulation Program Fortran (HSPF), the Soil and Water Assessment Tool (SWAT) that could be used in simulating the runoff. But we have taken the SWAT for the current study because it is widely used and it is user friendly in terms of handling input data (Arnold et al. 1998).

The objective this study was to assess the impact of past land use changes on streamflow of the Kolab river basin. The results obtained from this study will be helpful for understanding the interactions between the streamflow and land use change which is required for water resource planning.

2. Study Area:

In the present study was conducted for the Kolab river basin. The Kolab river originates from the western slopes of Eastern Ghats in Odisha state from Sinkaram hill ranges at 1370 m MSL. It is also known as Sabari river and it is one of the tributaries of Godavari river. Sileru river and Pateru river are the tributaries of this river. The annual average rainfall over this entire basin is approximately 1250 mm. The basin extends over states of Chhattisgarh, Odisha and Andhra Pradesh having a basin area of 20,427 Sq. km. which is approximately 1.6% of the total area of India with a maximum length of 418km. It lies between 81°15'37" E to 83° E longitudes and 17°34'13" N to 19° N latitudes. The topography of this region is undulating and highly dissecting. The climate of the region is tropical. Late December and early February are the coldest months. Mainly four seasons are there in the region throughout a single year. They are Hot Weather, South-west monsoon, post-monsoon and Cold Weather. December and February are the coldest months with minimum average temperature of 11.5°C. The average annual maximum temperature of the basin is 30.57° C. while the average annual minimum it is 18° C. April and May months are the hottest months with average temperature of 34.5°C.

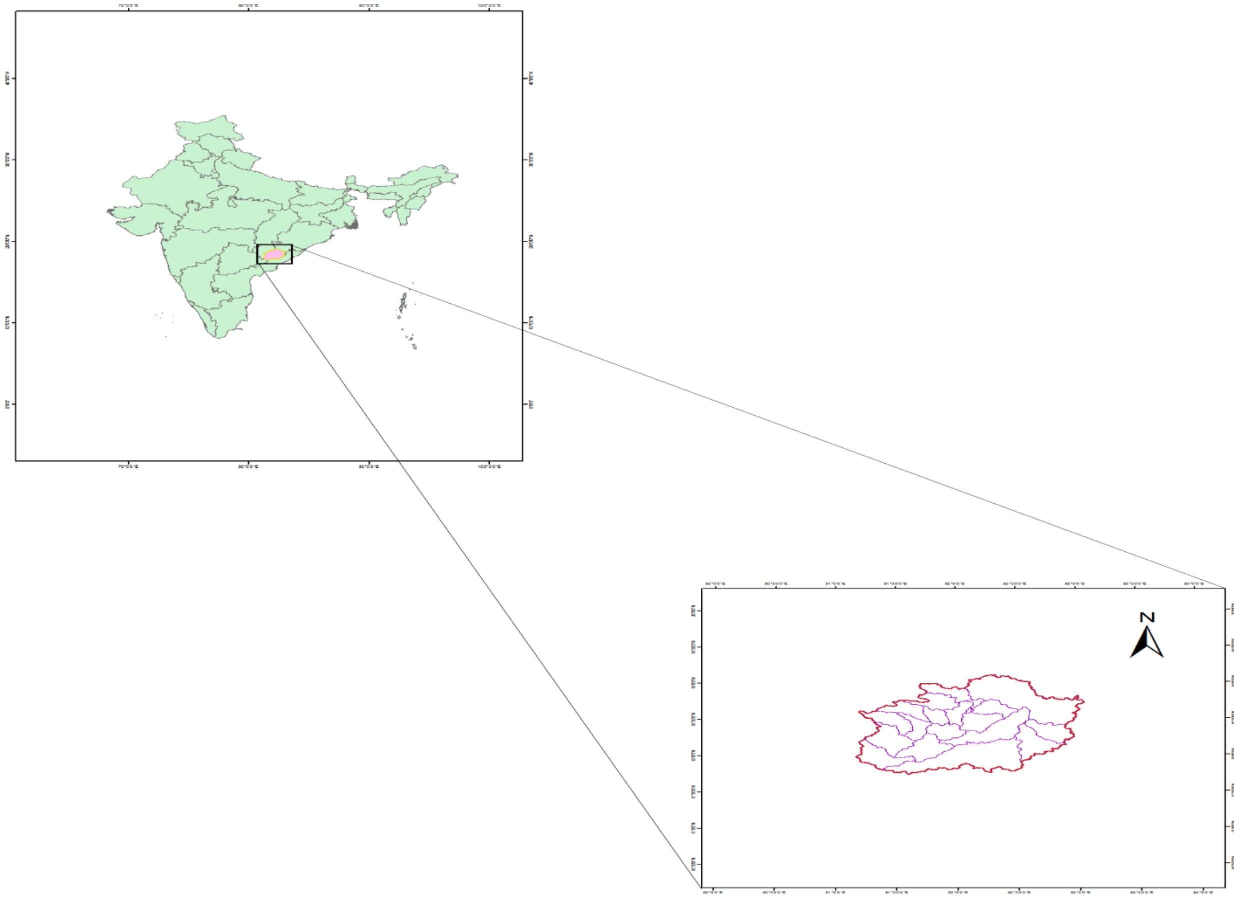


Fig.1. Location map of Kolab river Basin, India

3. Materials and methodology:

3.1 SWAT MODEL

SWAT, a semi-distributed, encyclopedic, physical based continuous hydrological model which is developed to predict the effects of land management on the hydrology, agricultural chemical yields and sediment yields in different watersheds under varying land use and soil conditions (Neitsch et al. 2009).

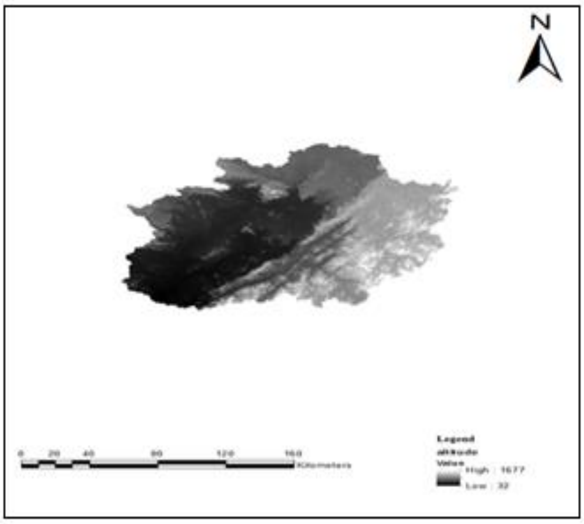
The framework of this model is to project the digital elevation model, land use/land cover and soil map into a standard projection system. HRUs are used for simplification of the model run by uniting all identical soils and land use areas into a single response unit. The model evaluates different hydrological parameters such as evapotranspiration, peak rate of runoff, surface runoff and other components by individual HRU using water balance equation. The SCS curve number procedure (USDA-SCS 1972) and Green and Ampt. infiltration method (Green and Ampt.1911) are two basic methods of the model for estimating the surface runoff and modified rational method for estimating peak runoff rate. The estimation of hydrologic cycle at individual HRU was carried out using water balance equation as follows

$$SW_t = SW_\circ + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

Where SW_t is the final soil water content in mm H_2O, $SW_\circ$ is the initial soil water content on day i in mm H_2O, t is the time of days, R_{day} the amount of precipitation on day i in mm H_2O, Q_{surf} is the amount of surface runoff on day i in mm H_2O, E_a is the amount of evapotranspiration on day i in mm H_2O, w_{seep} is the amount of water entering the vadose zone from soil profile on day i in mm H_2O, Q is the amount of return flow on the day i in mm.

3.2 SWAT MODEL INPUT DATA

The major inputs for the model required for simulation are land use map, soil cover map, digital elevation model, rainfall and temperature data (Table1). Shuttle radar topographic mission (SRTM) provides the digital elevation model data (DEMs) having a 90m resolution. These DEM data are available in the form of square-shaped tiles with a specific dimension. The DEM downloaded from SRTM website has projection system of WGS 1984 UTM, zone 44N at 90 m resolution. These DEMs were used for watershed delineation and those were also used to depict the streamflow, drainage pattern, flow accumulation and networks of the basin area.



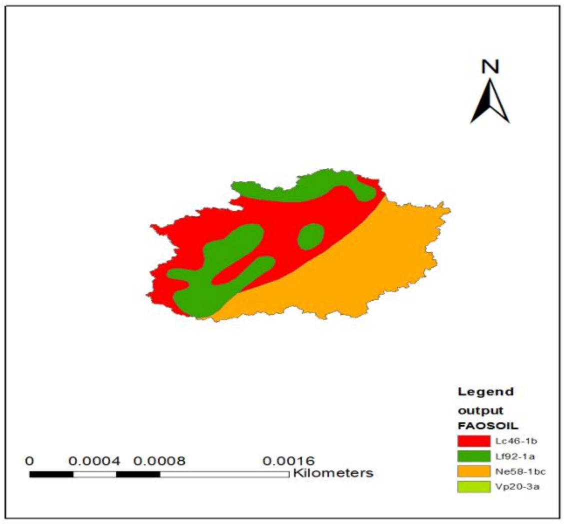
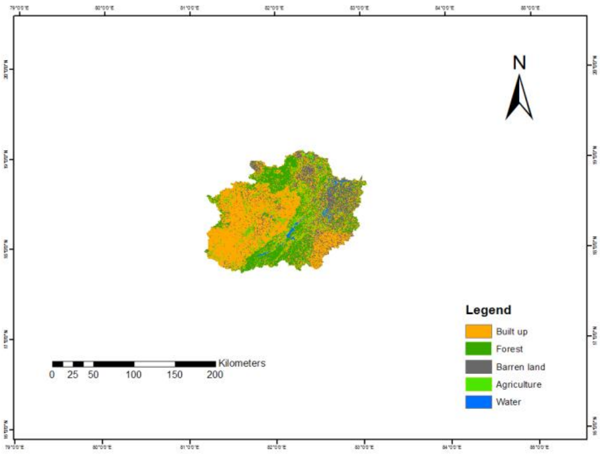


Fig.2a. Digital Elevation Model of the Basin

Fig. 2(b) Soil map of the basin.

Landsat 8 and Landsat 5 satellite images (spatial resolution 30 m) for 2013 and 1995 were obtained from earthexplorer in the form of tiles. Fig. 2(c) shows, the land use maps, used in SWAT simulation. Soil map was prepared using FAO digital soil map of the world having a scale of 1:5,000,000. The meteorological parameters (precipitation, maximum and minimum temperature, relative humidity, solar radiation, wind speed etc.) control the hydrological cycle. The meteorological data for 1979 to 2013 were collected from The National Centers for Environmental Prediction (NCEP)



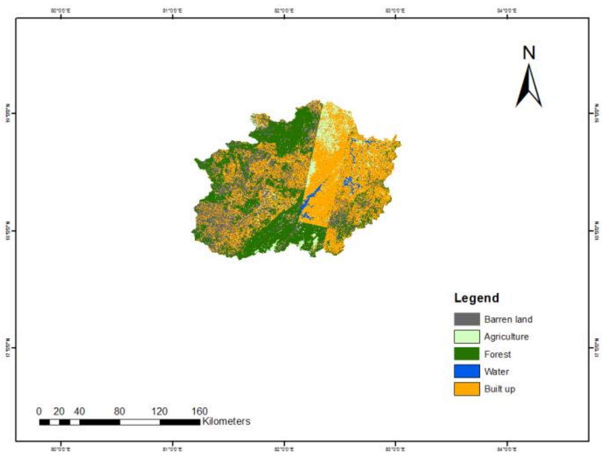


Fig.2(c) Landuse land cover map (1995)

Fig. 2(d) Landuse land cover map (2013)

Table 1: Different land use land cover area in Kolab basin

ID	LAND COVER SPECIFICATION	1995	2013	CHANGE
		AREA(KM^2)	AREA(KM^2)	(%)
1	Built up	8460.21	10463.36	(+) 0.09
2	Forest	5820.38	4129.23	(-) 0.08
3	Barren Land	4314.67	3450.04	(-) 0.04
4	Agriculture	1387.56	1929.89	(+) 0.02
5	Water	239.48	250.04	(+) 0.0005

Table 2 . Spatial model input data for the Kolab River catchment

Data type	Description	Resolution	Sources
Topographic map	Digital elevation map (DEM)	90 m	SRTM
Land-use map	Land-use classification	30 km	Landsat 8 &5 (USGS)
Soil map	Soil types	10 km	FAO
Weather	Daily precipitation,	-	NCEP
Hydrological data	Discharge	-	WRD, Koraput

3.3 SWAT MODEL SETUP AND SIMULATION

Arc SWAT 12, an interface of SWAT model in ArcGIS 10.1. It was used to establish the SWAT model of the Kolab basin. To develop the model the following five steps are needed: (1) sub-basin discretization; (2) HRU definition; (3) climate station formation; (4) parameter sensitivity analysis; (5) calibration and validation.

The digital elevation model data was used to delineate the area of Kolab basin along with the stream networks using Arc SWAT 12. The Kolab basin had produced 20 HRUs based on soil and land use-land cover data. The simulation of the model was done for the year of 1979 to 2013 on daily time step with a warm-up period of five years. Fig. 3 shows the schematic diagram of complete methodology of this study.

3.4 SENSITIVITY ANALYSIS, CALIBRATION AND VALIDATION

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

Calibration is examining the precision of a measurement instrument by comparing it to reference standards. In this present study 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 (R2) and the percent bias (PBIAS) were used. (Moriasi,2007).

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

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i - S_i) * 100}{\sum_{i=1}^{n}(O_i)} \quad (3)$$

$$RSR = \frac{\sqrt{\sum_{i=1}^{n}(O_i - S_i)^2}}{\sqrt{\sum_{i=1}^{n}(O_i - O)^2}} \quad (4)$$

$$R^2 = \frac{[\sum_{i=1}^{n}(O_i - O)(S_i - S)]^2}{\left[\sum_{i=1}^{n}(O_i - O)^2\right] * [\sum_{i=1}^{n}(S_i - S)^2]} \quad (5)$$

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 illustrates the prediction ability of hydrological model by comparing the simulated output to the observed data. It ranges from -∞ to 1. NSE value close to 1, indicates the model is accurate. R2 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 R2 varies from 0 to 1. An R2 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).

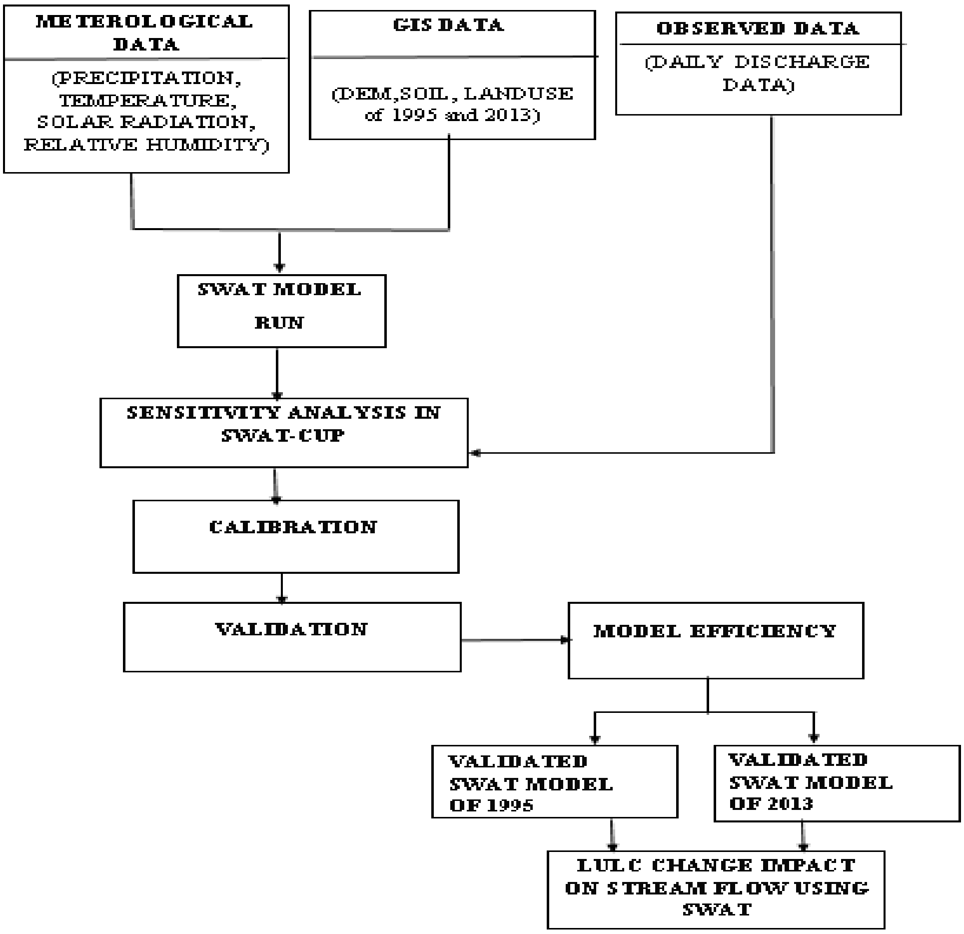


Fig. Schematic diagram of methodology

4. Result and Discussion

Only six parameters out of fourteen were very sensitive in Global sensitivity analysis. Based on the sensitiveness the sensitive parameters are presented for 1995 land use (LU) scenario model (Table). 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 Table4.

Table 3: Sensitivity Analysis of streamflow parameters for 1995 scenario model

SL.No.	Parameter name	t-stat	p-value
1	CH_K2 (Effective hydraulic conductivity in main channel alluvium)	9.205	0.000
2	CN2 (SCS runoff curve number)	5.921	0.000
3	ALPHA_BNK (Base-flow alpha factor for bank storage)	5.266	0.000
4	SOL_K (Saturated hydraulic conductivity)	2.320	0.000
5	GW_REVAP (Groundwater "revap" coefficient)	-1.922	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 4: Ranges and best-fitted values of flow calibration parameters

Rank	Parameter name	Fitted value	Minimum value	Maximum value
1	v_GW_DELAY.gw	169.249	30.000	440.000
2	r_CN2.mgt	0.068	-0.200	0.200
3	r_SOL_K.sol	0.087	-0.800	0.800
4	v_ALPHA_BF.gw	0.503	0.000	1.000
5	v_GW_REVAP.gw	0.018	0.000	0.200

In the second case, the result was showed with the help of land use scenario model (2013). Here in this study only five parameters were sensitive to stream flow. 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 stream flow in the catchment as their p-values were greater than 5% (Anaba et al., 2017).

Table 5: Sensitivity Analysis of stream flow parameters for 2013 scenario model

SL.No.	Parameter name	t-stat	p-value
1	CH_K2 (Effective hydraulic conductivity in main channel alluvium	-2.986	0.001
2	CN2 (SCS runoff curve number)	11.001	0.000
3	ALPHA_BNK (Base-flow alpha factor for bank storage)	13.536	0.000
4	SOL_K (Saturated hydraulic conductivity)	3.020	0.002
5	GW_REVAP (Groundwater “revap” coefficie	-1.556	0.120
6	REVAPMN (Threshold depth of water for revap or percolation to occur)	-1.129	0.259
7	GWQMN (Threshold depth of water in the shallow aquifer required for return flow to occur)	0.983	0.326
8	HRU_SLP (Average slope steepness)	0.805	0.414
9	CH_N2 (Manning’s “n” value for the main channel)	-1.301	0.193
10	SOL_AWC (Available water capacity of the soil layer)	-3.129	0.000
11	ESCO (Soil evaporation compensation factor)	-2.035	0.042
12	ALPHA_BF (Base-flow alpha factor)	0.707	0.479
13	GW_DELAY (Groundwater delay)	0.397	0.691
14	SLSUBBSN (Average slope length)	1.668	0.095

Table 6: Ranges and best-fitted values of flow calibration parameters

Rank	Parameter name	Fitted value	Minimum value	Maximum value
1	v_ALPHA_BNK.rte	0.849	0.000	1.000
2	r_CN2.mgt	0.114	-0.200	0.200
3	r_SOL_K.sol	0.059	-0.200	0.400
4	v_CH_K2.r	110.425	5.000	130.000
5	v_ESCO.hru	0.775	0.800	0.100

4.1 SWAT MODEL CALIBRATION AND VALIDATION RESULT

The calibrated (Fig.7a) and validated (Fig.7b) results for 1995 LU model shows the graphical representation of stream flow. 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).

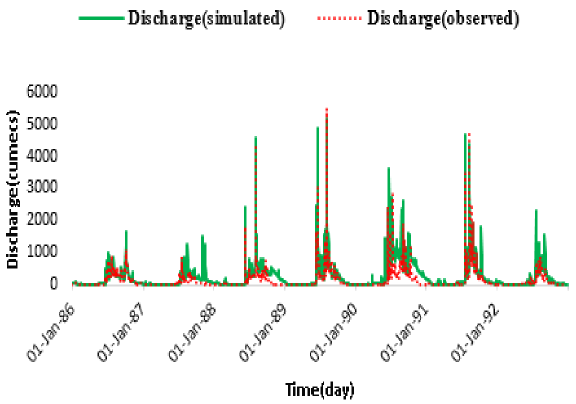


Fig.7(a). Observed and simulated daily discharge during calibration period (1986-1992) for 1995 LU model

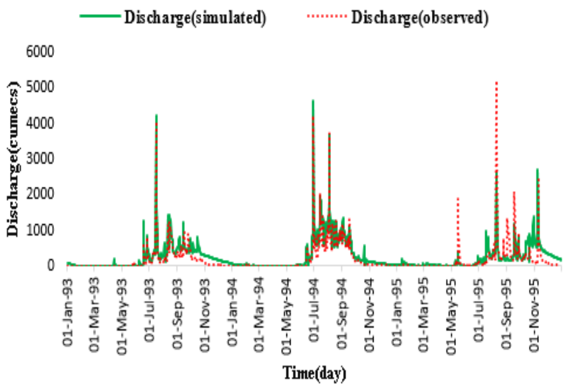


Fig.7(b). Observed and simulated daily discharge during validation period (1993-1995) for 1995

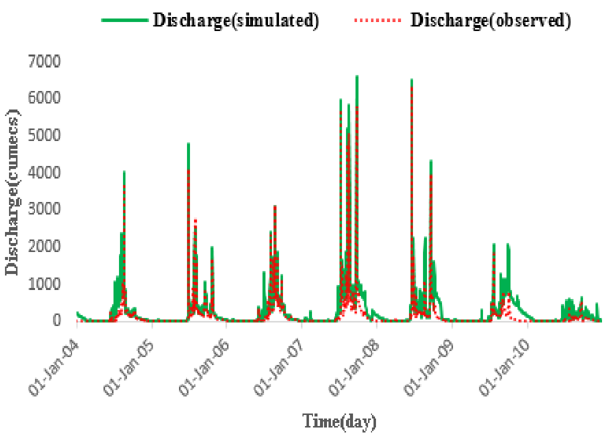


Fig. 8(a). Observed and simulated daily discharge during calibration period (2004-2010) for 2013 LU model

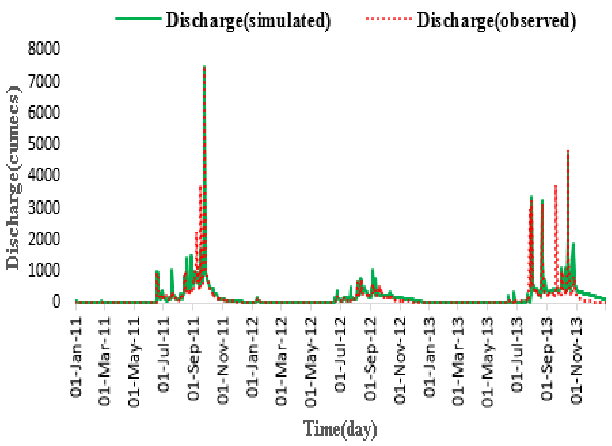


Fig.8(b). Observed and simulated daily discharge during calibration period (2011-2013) for 2013 LU model

Table 7: SWAT model calibration and validation statistical objective function

Stages of model	Statistical parameters			
	R^2	NSE	RSR	PBIAS
Calibration (1986-1992)	0.601	0.568	0.413	-14.0
Validation (1993-1995)	0.573	0.519	0.452	-19.0
Calibration (2004-2010)	0.588	0.523	0.465	-12.0
Validation (2011-2013)	0.533	0.509	0.471	-16.0

4.2 MODELLING STREAM FLOW RESPONSE TO LAND USE DYNAMICS

Establishing scenarios to assess impacts of land-use

The impact assessment of land use changes on streamflow under different scenarios were established by SWAT 2012. The one factor at a time approach (Li et al., 2009) was taken into consideration.

Scenario I: Climate of 2007-2013 and land use of 2013.

Scenario II: Climate of 2007-2013 and land use of 1995.

Scenario	Mean annual Streamflow (m3/s)
I	224.93
II	219.22
Change (I-II) with respect to scenario II	+2.71%

5. Conclusion

The present study signified that the Kolab river basin has experienced a remarkable change in those eighteen years. This study shows the increment of built up area (0.09%), agricultural area (0.02%) and decrement of area covered by the forests (0.08%), barren land (0.04%). As a result of calibration and validation the SWAT model gives a convenient result for the stream flow simulation. It specifies that the stream flow for the present as well as future scenarios, which can be reliable for Kolab basin. Under a constant climate condition, using two land-uses of 1995 and 2013, it was clear that due to land use changes the stream flow has increased by 2.71%. So the impacts of land use changes and the stream flow are co related to each other and the study will be helpful for management of the watershed.

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