IMPACT OF LAND USE LAND COVER CHANGE ON RUN OFF GENERATION IN TUNGABHADRA RIVER BASIN

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ABSTRACT:

Streamflow can be affected by a number of aspects related to land use and can vary promptly as those factors change. Urbanization, deforestation, mining, agricultural practices and economic growth are some of the factors related to these land use changes which alter the stream flow. In the present study, the impact of land use land cover change (LULC) on stream flow is studied by using SWAT model for Tungabhadra river basin, located in the state of Karnataka, India. Tungabhadra river originates in the Western Ghats of Karnataka and flows towards north-east and joins the river Krishna. The land use maps of 1993, 2003 and 2018 are used for assessing the stream flow changes with respect to LULC. Calibration and validation of the model for streamflow was carried out using the SUFI-2 algorithm in SWAT-CUP for the years 1983-1993 and 1994-2000 respectively. Statistical parameters namely Coefficient of Determination (R^2) & Nash–Sutcliffe (N-S) were used to assess the efficiency and performance of the SWAT model. It was found that the observed and simulated streamflow values are closely matching, which in turn projects that the model results are acceptable. The calibrated model was used for simulation of future dynamic land use scenario to assess the impact on streamflow. The results can be used for conservation of water and soil management.

KEYWORDS: Land Use Change, SWAT-CUP, SWAT Model, Statistical Parameters, Runoff

1. INTRODUCTION

Land Use Land Cover change is a crucial environmental change which has several impacts on human livelihoods. Management of earth's natural resources remains a critical environmental challenge that society must address because misuse of available resources may lead to severe threat causing scarcity of water resources. Natural life is mainly supported by major resources i.e. water and soil, which play crucial roles in the natural ecosystems. Freshwater which moves from upstream to downstream is mainly supplied by the watersheds. The water quality reaching the downstream is being degraded due to the changes that are occurring in land use and land cover. Changes in land use and land cover mainly drive the changes in watershed hydrology. Deforestation, conversion of vegetation lands to agriculture may increase the economic development but it also affects the environmental status of the society. [*]

Stream flows are sensitive to land use change i.e. minor change in land use causes major changes to stream flows. Numerous studies have been conducted to investigate the impact of LULC change on stream flows ranging from small watersheds to large river basins which ended up exhibiting the causes for stream flow changes is due to conversion of forest land to agricultural lands. Increase in settlements, deforestation, expansion of agricultural area and intensive grazing yields high runoff and sediment yield. These changes enlarge the quantity, velocity and intensity of runoff. Considering this, Loi (2010) used two land use scenarios for assessing the factors that contribute to the change in runoff for Dong Nai watershed, Vietnam and Shrestha et al. (2015) used monthly stream flows and sediment yield data for assessing runoff and sediment yield from Da river basin in Northwest of Vietnam. Both of them applied SWAT model for simulating daily, monthly runoff and sediment yield and concluded that there is an increase in runoff and sediment yield when the land had been converted from forest to agriculture. The specific objective of the present study is to analyse the impact of LULC on stream flows from the past three decades which is important to understand the economic and environmental changes in the study area.

2. STUDY AREA

Tungabhadra River is a major tributary of river Krishna which originates from the confluence of two rivers Tunga and Bhadra which were started at Gangamoola of Western Ghats region of Karnataka at an altitude of 1198 m above MSL flowing towards eastern side and meeting at Holehonnur at an altitude of 610 m in Shimoga. The Tungabhadra river basin has a total catchment area of about 69552 km^2 which includes both upper and lower Tungabhadra river basins but the current study area lies between longitudes 74°00′00″–76°30′00″E and latitudes 13°00′00″–15°30′00″N, with a catchment area of 15393.039 km^2 up to the Haralahalli gauge station, which is at the outlet of the catchment as shown in Figure 1. The average annual temperature of the region is around 26˚ C with mean maximum monthly temperature varying from 26.3˚C to 35.5˚C and mean minimum monthly temperature varying from 13.8˚C to 22.3˚C. The average annual rainfall recorded over the region is about 1200 mm (Lo Porto et al. 2010).

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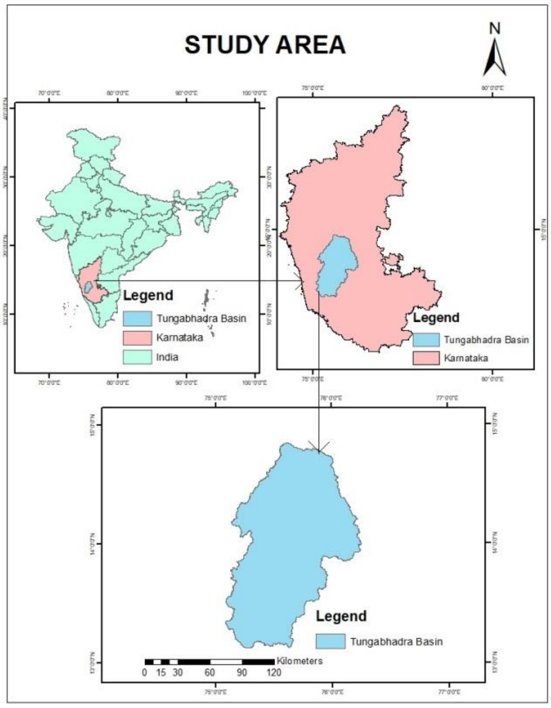

Figure 1. Study Area

3. DATA USED IN THE STUDY

Soil and Water Assessment Tool (SWAT) model was deployed in the present study for the simulation of runoff for Tungabhadra river basin. SWAT requires raster files such as DEM, land use and slope maps and vector datasets such as outlet points, rainfall and temperature for the generation of runoff. All the input datasets must be projected to WGS 1984 World Mercator for loading them into SWAT. The input datasets are mainly categorized into 4 categories viz. Topography, Land use, Soil and Hydrometeorological datasets for simulating the stream flow processes.

3.1 Topography:

Topography is mainly represented in the form of Digital Elevation Model (DEM) as shown in fig 2. Shuttle Radar Topography Mission (SRTM) DEM which represents the topography of the study area with a spatial resolution of 30m is downloaded from USGS Earth Explorer. DEM gives elevation values for each pixel and it is used for delineating the watershed in SWAT model. SRTM DEM obtained from USGS Earth Explorer has some voids which should be filled for processing into SWAT. In order to fill these voids ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM was used which has the same spatial resolution of 30m. Raster calculator in ArcGIS is used for filling these voids by overlaying ASTER DEM and SRTM DEM. Slope map was generated from DEM depending upon the steepness of the surface. The study area is divided into 5 slope classes as shown in figure 3, viz. 0-10, 10-20, 20-30, 30-40 and >40.

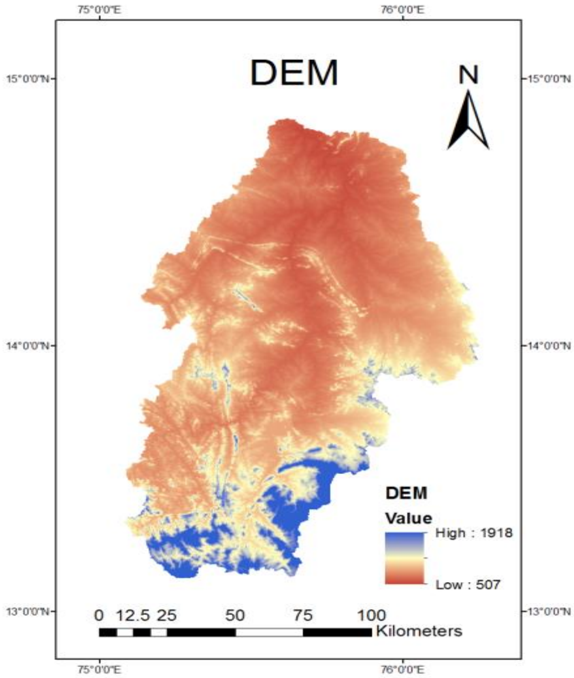

Figure 2 DEM

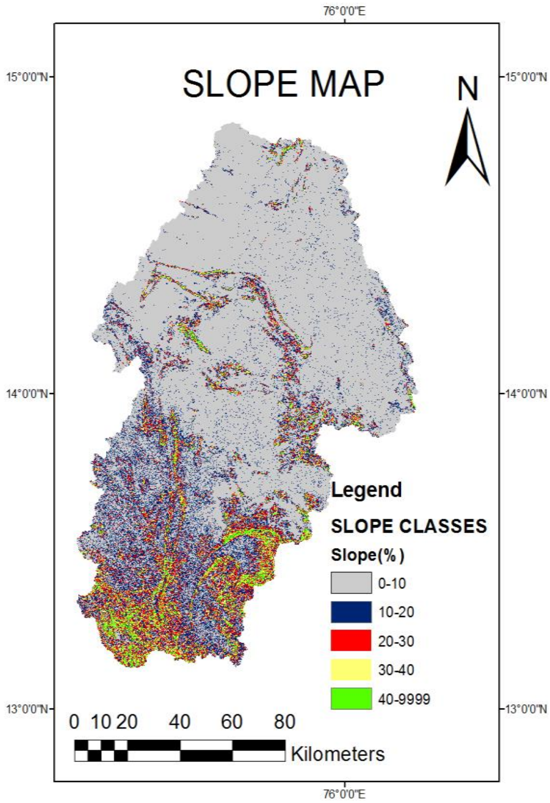

Figure 3 Slope map

3.2 Soil Map

Soil map was obtained from the FAO (Food and Agricultural Organization) database which is having a scale of 1:5000000. FAO soil map is available at global scale which is then clipped to the study area. Based on the soil type, the catchment was classified into 7 categories as mentioned in fig 4 by FAO map.

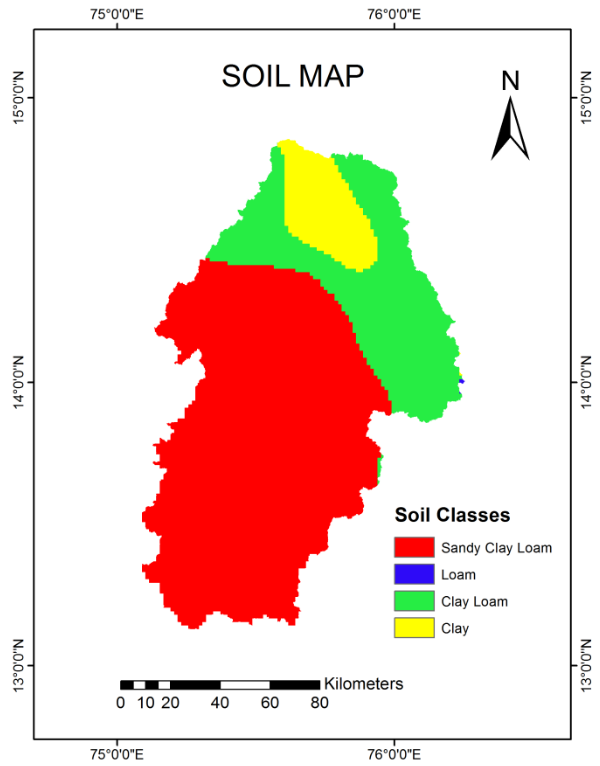

Figure 4 Soil map

3.3 Weather Data

Hydro-Meteorological data namely rainfall and temperature are obtained from Indian Meteorological Department (IMD) for the years 1980 to 2014. Precipitation and temperature are in gridded format with an interval of 0.5˚ and 1.0˚ respectively. Other parameters such as relative humidity, solar radiation and wind speed are established by weather generator in SWAT. This gridded data is prepared by IMD by considering 1803 precipitation stations all over India.

3.4 Land Use Land Cover Map:

Three land use land cover datasets are created for the years 1993, 2003 and 2018 by downloading, layer stacking and mosaicking Landsat 5, 7 and 8 satellite images from USGS Earth Explorer which are free from cloud cover (Details are shown in Table 9). The mosaicked images are further processed for land use land cover classification using ERDAS Imagine software using Maximum Likelihood algorithm. The land use land cover datasets are divided into 7 classes namely agriculture (AGRL-All varieties of crops and plantations are considered as agriculture), barren (BARR-Rocks, Hills, Wastelands), built up (URBN), cultivated land (RNGE-Agricultural land which was left unseeded for some years), forest (FRST), mining (SWRN) and water body (WATR). The agricultural land will intercept at least some part of the rain whereas cultivated lands were vacant which contributes more runoff as no interception occurs when compared to agricultural lands.

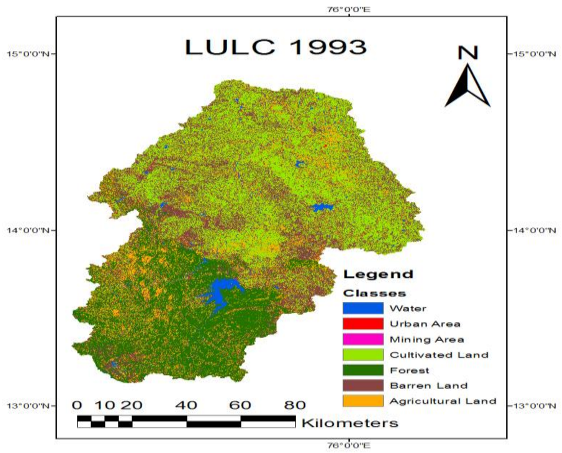

Figure 5 Land use land cover map of 1993

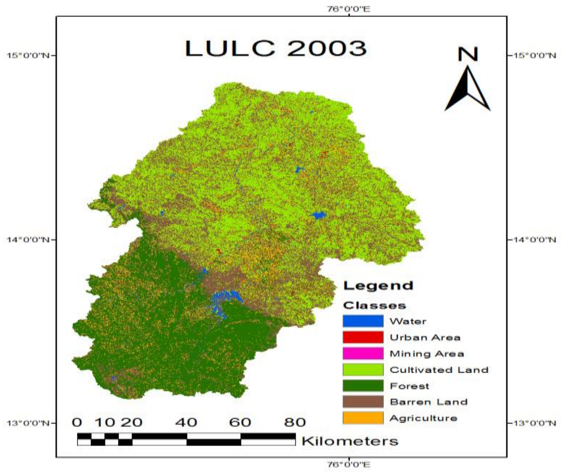

Figure 6 Land use land cover map of 2003

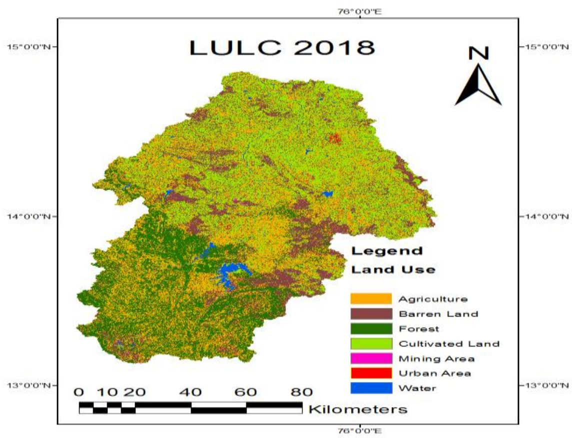

Figure 7 Land use land cover map of 2018

LULC TYPE	1993 Total (%)	2003 Total (%)	2018 Total (%)
Barren Land	30.35	31.57	22.18
Mining Area	0	0	0.16
Agriculture	10.73	6.3	24.04
Cultivated Land	34.58	35.81	31.76
Forest	22.3	25.24	19.65
Water	1.93	0.96	1.45
Urban Area	0.11	0.12	0.76
Overall accuracy	84.53	86.33	85.94
Kappa coefficient	0.774	0.744	0.789

Table 8 Land use land cover statistics

Year	1998	2003	2018
Satellite ID	LANDSAT-5	LANDSAT-7	LANDSAT-8
Sensor	Thematic Mapper	Enhanced Thematic Mapper Plus	Operational land imager (OLI) & Thermal infrared sensor(TIRS)
Path/Row	Date acquired	Date acquired	Date acquired
145/050	06/02/1998	27/01/2003	28/01/2018
145/051	10/03/1998	27/01/2003	28/01/2018
146/050	13/02/1998	19/02/2003	04/02/2018

Table 9 Details of Land Use Land Cover datasets

4 METHODOLOGY

4.1 SWAT Model:

SWAT (2012) model is used in this study with an Arc GIS extension to setup the hydrological model of Tungabhadra river basin. SWAT is physically based continuous time domain model which uses readily available inputs for predicting various parameters related to water, sediment and agricultural chemical yields for all types of watersheds at daily, monthly and annual time steps (Arnold et al. 1995). The entire basin is divided into multiple Hydrological Response Units (HRU's) by SWAT which has unique land, soil and slope characteristics. The land use, soil map and slope map are overlaid and threshold values are specified to divide into watershed into multiple sub-basins and HRU's. Once the overlaying was completed, Meteorological parameters were inserted and the setup of SWAT was done. The SWAT model was run with uniform soil data (FAO) and meteorological parameters (precipitation and temperature gridded datasets of IMD for the years 1980 to 2000) assuming that the climate change is negligible during the time frame for the 3 LULC datasets.

The hydrological processes in SWAT are mainly generated based on soil water balance equation (Neitsch et al. 2011).

$$SWt = SWo + \sum_{i=1}^{n}(\text{Rday - Qsurf - Ea - Wseep – Qgw})$$

where SWt = final soil water content (mm H2O); SWo = initial soil water content (mm H2O); t = time (days); Rday = amount of precipitation on day i (mm H2O); Qsurf = amount of surface runoff on day i (mm H2O); Ea = amount of evapotranspiration on day i (mm H2O); Wseep = amount of percolation and bypass exiting the soil profile bottom on day i (mm H2O); Qgw = amount of return flow on day i (mm H2O). Actual Evapotranspiration and potential transpiration are calculated based on Penmann- Monteith method. Surface runoff and peak runoff are estimated based on modified Soil Conservation Service (SCS-CN) method and the modified rational method.

4.2 **SWAT-CUP:**

Sequential Uncertainty Fitting (SUFI-2) algorithm within SWAT-CUP (Abbaspour et al.) is used for calibration and validation. The streamflow records are obtained from India-WRIS website for Harlahalli gauging stations over a period of 21 years ranging from 1980 to 2000. The entire duration is divided into 3 years for the warm-up period, 12 years ranging from 1983 to 1994 for calibration and 6 years ranging from 1995 to 2000 for the validation period. Calibration and validation are mainly based on sensitive parameters in SWAT-CUP. Parameters are said to be sensitive if a small change in the parameter ranges causes a large change in the runoff. Sensitivity analysis is carried out to identify the parameters which are sensitive to a particular region. Sensitivity analysis is useful for decreasing the number of sensitive parameters if they found insignificant. The t-stat and p-value in the SUFI-2 algorithm is useful for finding the sensitivity of parameters. The p-value determines the significance of sensitivity based on the value ranging from 0 to 1. The value closer to zero is identified as the most sensitive parameter and vice-versa.

Different statistical coefficients like the Coefficient of Determination (R^2) and Nash-Sutcliffe (N-S) are used for finding the accuracy of model performance. R^2 gives the correlation between observed and simulated values which ranges from 0 to 1 and N-S shows relative difference between observed and simulated values which ranges from -∞ to 1.

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5. RESULTS AND DISCUSSIONS:

5.1 Comparison of Land Cover Datasets

Supervised classification was performed with maximum likelihood algorithm in ERDAS Imagine software for classifying land use land cover datasets of Landsat satellite imagery. All the 3 datasets (1993, 2003, 2018) are categorized into 7 classes as shown in figs .5,6,7. The distribution of three land use land cover datasets over 7 classes were examined and are presented in table 8. Based on the results it is observed that the study area is mainly dominated by cultivated land in all the 3 years (34.58%, 35.81%, 31.76%) followed by barren land and forest in 1993, 2003 and agriculture and barren land in 2018. It is noticed that agricultural land in 2018 was increased twice (10.73% to 24.04%) when compared to 1993 and 4 times (6.3% to 24.04%) when compared to 2003.The forest area was increased by 2.94% in 2003 when compared to 1993 which is due to the increase of shrub and grasslands in the areas of agriculture leading to the decrease in agricultural land in 2003. The urban area was expanded from 0.11% to 0.76% within 3 decades. The percentage changes are mentioned in figure 10 where barren land was decreased in 2018 when compared to 1993 and some part of the barren land was converted to mining area and some percentage to urban and agricultural lands. Three LULC datasets of different years are used in this study to identify whether the changes in land use affect the quantity of stream flow. The average annual runoff values during the calibration period were 363.44, 361.39, 350.89 mm and 435.76, 433.95, 424.46 during the validation period for the years 1993, 2003 and 2018. From these results it is observed that even though there are larger changes in percentage occupancies of land use, there is less influence on runoff.

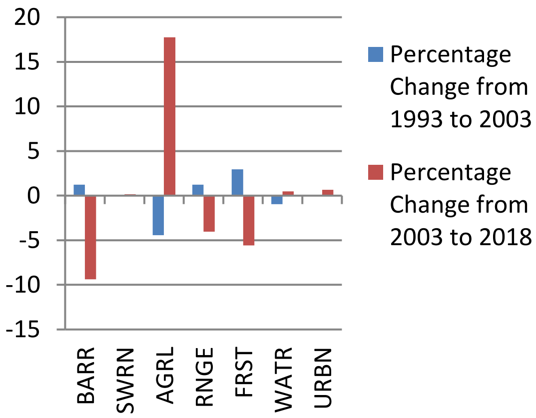

Figure 10 Percentage changes of LULC from 1993 to 2018

The water area was decreased from 29634 ha to 14814 ha from 1993 to 2003 and was increased to 22259 ha in 2018. The overall accuracy was found to be 84.53%, 86.33% and 85.94% for the years 1993, 2003 and 2018. Kappa statistics was determined which was found satisfactory with a result of 0.774, 0.744 and 0.789 for the 3 years respectively.

5.2 Calibration and Validation:

Sensitivity analysis was performed prior to the calibration of the model. Out of 18 parameters obtained from the previous literature, 10 parameters were found to be sensitive. Table 11 represents the sensitive parameters, allowable ranges that are available in SWAT-CUP and the fitted values which were obtained from calibration result. Out of 10 parameters that are found sensitive, ESCO, CN2, SOL_K has a P-value of 0 with rankings of 1,2 and 3 followed by CH_N2, GW_DELAY, GWQMN, ALPHA_BF,CH_K2, SOL_AWC and ALPHA_BNK.

Sensitive Parameters	Allowable Range	Fitted Value
CN2 (SCS runoff curve number)	-0.2 to 0.2	-0.18
Alpha-BF (Base flow alpha factor (days))	0 to 1	0.71
GW-Delay (Groundwater delay (days))	0 to 500	277.75
GWQMN (Threshold depth of water in the shallow aquifer required for return flow to occur (mm))	0 to 5000	1.805
ESCO (Soil evaporation compensation factor)	0 to 1	0.021
CH_N2 (Manning's "n" value for the main channel)	-0.01 to 0.3	0.149
Alpha_BNK (Base flow alpha factor for bank storage)	0 to 1	0.248
CH_K2 (Effective hydraulic conductivity in main channel alluvium.)	-0.01 to 500	193.06
Sol_K (Saturated hydraulic conductivity)	0 to 2000	60.9

Table 11 Sensitivity parameters for SWAT-CUP

The model was calibrated and validated at daily and monthly time steps with a calibration period of 12 years ranging from 1983 to 1994 and validation period of 6 years ranging from 1995 to 2000.

Table 12 and 13 lists the statistical coefficient values which represent the accuracy of model performance. At daily time step, the R^2 and N.S haven’t exhibited much difference for all the three years (1983, 2003 and 2018) during calibration and validation which has R^2 around 0.73 and N.S around 0.68. Monthly results were greatly improved which has $R^2 > 0.8$ and N.S > 0.79 for all the 3 years.

Stastical Coefficient	LULC 1993		LULC 2003		LULC 2018	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
R^2	0.727	0.753	0.729	0.754	0.73	0.75
N.S	0.73	0.68	0.73	0.69	0.73	0.68

Table 12 Statistical coefficient values for daily runoff

Stastical Coefficient	LULC 1993		LULC 2003		LULC 2018	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
R^2	0.8	0.852	0.804	0.854	0.8	0.85
N.S	0.79	0.847	0.79	0.793	0.79	0.828

Table 13 Statistical coefficient values for monthly runoff

Scatter plots are plotted for observed against simulated runoff values which are shown in figures 14, 15, 16, 17. Line graphs are plotted for observed and simulated streamflows against time for the years 2003 and 2018 and are shown in Figs. 18, 19, 22, 23.

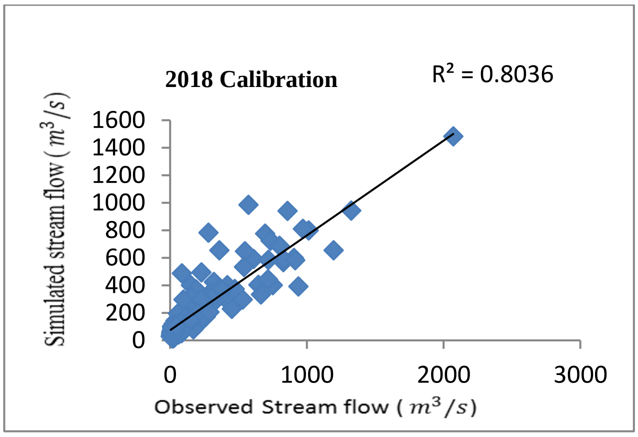

Figure 14 Plot showing simulated vs observed runoff at monthly time step for the year 2018(Calibration)

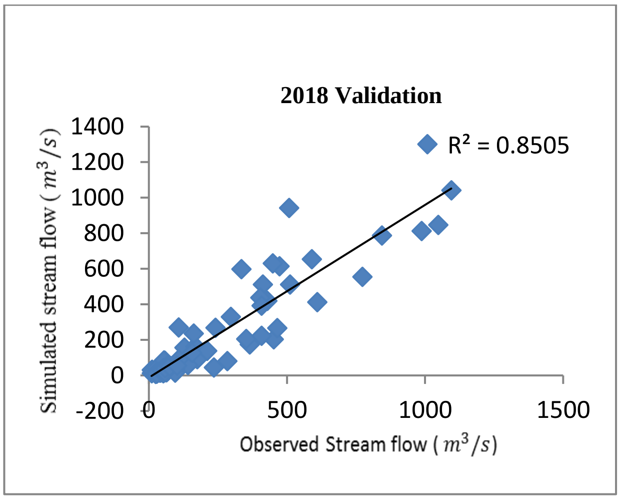

Figure 15 Plot showing simulated vs observed runoff at monthly time step for the year 2018(Validation)

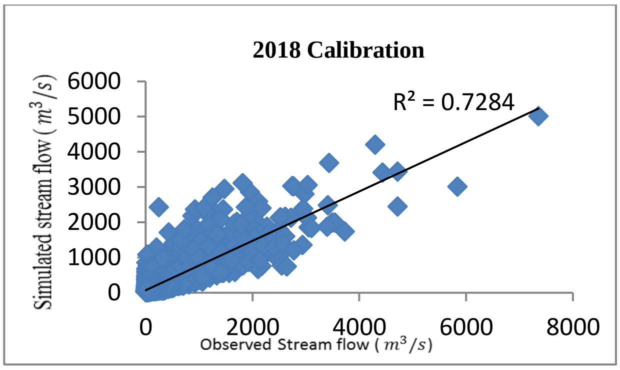

Figure 16 Plot showing simulated vs observed runoff at daily time step for the year 2018(Calibration)

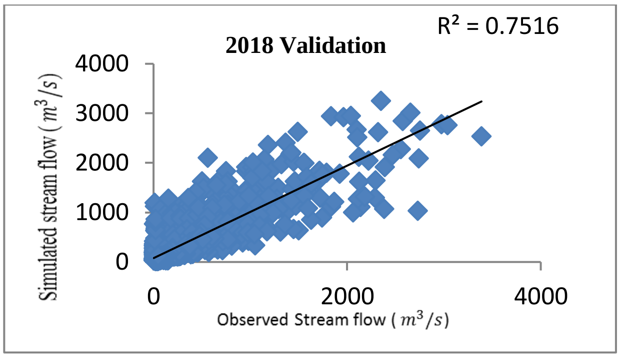

Figure 17 Plot showing simulated vs observed runoff at daily time step for the year 2018 (Validation)

Line graphs indicated that simulated values are underpredicted when compared to the observed runoff in most of the cases during the calibration period and are overpredicted during validation phase at daily time steps. The simulated runoff correctly depicted the peaks and base flow at monthly time steps.

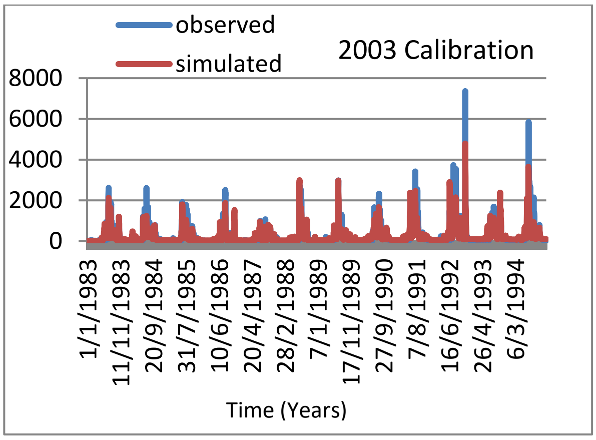

Figure 18 Line graph showing simulated and observed runoff vs time at daily time step for the year 2003 (calibration)

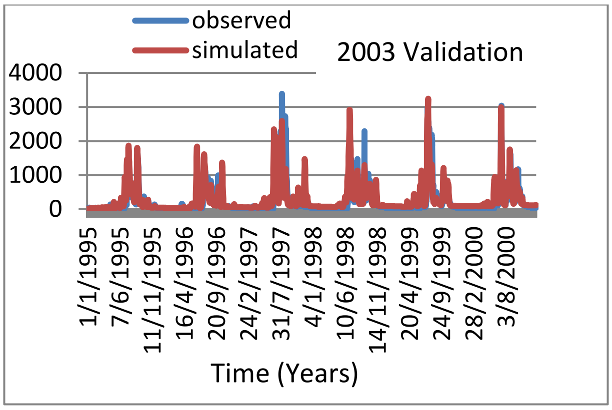

Figure 19 Line graph showing simulated and observed runoff vs time at daily time step for the year 2003 (Validation)

Calibration Phase		1993		2003		2018	
		Obs	Sim	Obs	Sim	Obs	Sim
Daily	STD Dev	451	372	451	369	451	370
	Peak	7357	4832	7357	4788	7357	5015
Monthly	STD Dev	326	259	326	251	326	250
	Peak	2071	1517	2071	1486	2071	1483

Table 20 Streamflow characteristics during calibration phase

Validation Phase		1993		2003		2018	
		Obs	Sim	Obs	Sim	Obs	Sim
Daily	STD Dev	393	426	393	423	393	423
	Peak	3388	3263	3388	3244	3388	3255
Monthly	STD Dev	290	306	290	302	290	306
	Peak	1294	1203	1294	1190	1294	1202

Table 21 Streamflow characteristics during validation phase

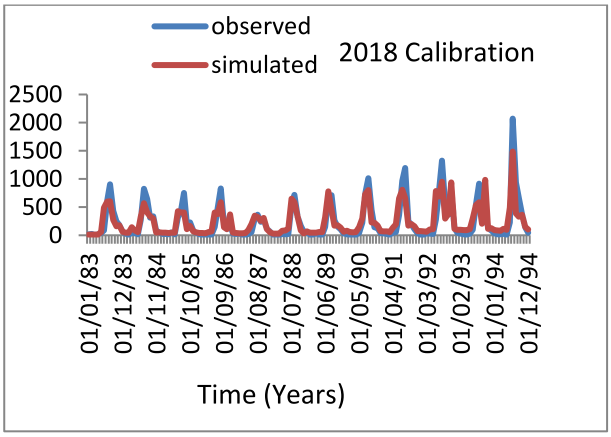

Figure 22 Line graph showing simulated and observed runoff vs time at monthly time step for the year 2018 (calibration)

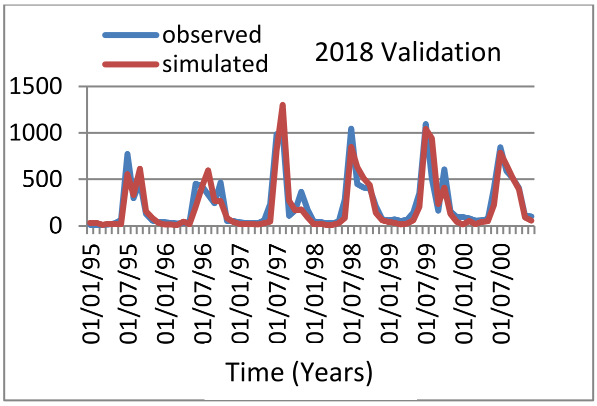

Figure 23 Line graph showing simulated and observed runoff vs time at monthly time step for the year 2018 (validation)

Table 20 & 21 gives the peak values and standard deviation values for both observed (Obs) and simulated (Sim) runoffs for the years 1993, 2003 and 2018 during the calibration and validation phases. From Table 20, it is evident that the peak values during the Observed period were much larger than the Simulation period for both daily and monthly phases and can also be observed in figures 18 and 22. The SWAT model was unable to match the peaks since there is a larger deviation between the observed and simulated values in the calibration phase. Table 21 exhibits that the peaks are closely matching and the deviation between the observed and simulated values are also less. The observed values have more standard deviation than the simulated values in the validation phase, due to which the N-S values during the validation phase in all the 3 years was less when compared to the calibration phase. The overall results exhibited good performance in simulating runoff using SWAT for Tungabhadra river basin during the 3 time periods. It is observed that, the change in LULC in 3 time periods did not show much difference between the simulated streamflow values. The accuracy can further be improved by implementing a soil map with better classification and high-resolution LULC maps.

6 CONCLUSIONS

The following conclusions are drawn from this study based on the SWAT model.

Based on LULC classification, the predominant classes are barren and cultivated land. Both the classes were decreased in 2018 when compared to 1993 which was accompanied by the increase in agriculture and urban area.

So many studies (Loi et al. 2010, Ngo et al. 2015) concluded that the conversion of forest to agricultural land increases the runoff. In the present study, even though there are significant changes in the LULC for the 3 decades, especially the decrease of forest and increase of agricultural land during the years 2003 and 2018, there was no significant change in the average annual runoff during the calibration and validation phases for the years 1993, 2003 and 2018.

Based on sensitivity analysis CH_N2, GW_DELAY, GWQMN, ALPHA_BF, CH_K2, SOL_AWC and ALPHA_BNK, ESCO, CN2, SOL_K were found to be sensitive for SWAT model employed in Tungabhadra river basin.

For daily simulations the results are good (R^2 = 0.727, 0.729, 0.73 during calibration phase and R^2 = 0.753, 0.754, 0.75 during validation phase) for the years 1993, 2003 and 2018

At monthly time step the results are further improved for runoff (R^2 = 0.8, 0.804, 0.8 during calibration phase and R^2 = 0.852, 0.854, 0.85 during validation phase) for the 3 years respectively.

The statistical coefficients (R^2 and N.S) were proved effective which exhibits that the SWAT model is capable of simulating runoff in the study area accurately.

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