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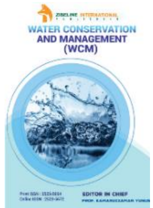

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RESEARCH ARTICLE

INFLUENCE OF LAND USE LAND COVER CHANGE ON RUNOFF CHARACTERISTICS OF NETRAVATHI RIVER CATCHMENT, KARNATAKA, INDIA

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ABSTRACT

The effect of LU/LC on the streamflow characteristics of the Netravathi river basin, Karnataka, India, is studied using Soil and Water Assessment Tool (SWAT) model. Landsat images, soil map from FAO, ASTER DEM (30m grid) and streamflow data, forms the database for the present work. The most significant changes from 1981 to 2015, in the LU/LC includes agricultural land (31.86%), built-up area (67.9%), forest cover (-20.01%), coconut plantation (55.12%), other vegetation (-18.55%) and others (-11.82%). The verification of performance of model was carried out by the coefficient of determination values (R2 > 0.8) and N S E (NSE > 0.78) were obtained and hence proved that SWAT model performance in estimating streamflow.. The average streamflow is increased by 13.74% from 1981 to 2015, which is mainly due to dynamic changes in LU/LC. Hence, it can be concluded that changes in LU/LC have a direct impact on streamflow in the study area.

KEYWORDS

Soil and Water Analysis Tool (SWAT), Land Use/Land Cover, Digital Elevation Model (DEM), Image Classification

1. INTRODUCTION

Water is among the most important constituents of the hydrologic system. The availability of this water is largely governed by rainfall and this, in turn, being influenced by vegetation cover. So, management and utilization of water resources in proper manner are very essential for balancing the supply and demand of water. For this, detailed studies of the watershed and hydrologic changes are required. One among the important driving force is the changes in land use/ land cover (LU/LC) that affect hydrologic variations in the basin. For example surface runoff, infiltration, lateral flow and recharge of groundwater (Niehoff et al., 2002). Land use refers to a small portion of land utilized for activities such as the construction of buildings, road networks and other infrastructures. Land cover, on the other hand, is the natural cover such as rocky terrain, forest cover and water bodies. Land use is more important compared to land cover due to its multilevel economic and sociocultural values.

Generally, land use changes are limited to local and regional level whereas land cover occurs predominantly on a larger or global scale. It is very much essential to know the effects of LU/LC on streamflow since the information on streamflow is essential for watershed monitoring and management. The effect of LU/LC changes on streamflow and its quantification is one of the exciting areas of research in hydrology (Kristian 1998; Coutu et al., 2007; Sajikumar and Remya, 2015). The combination of hydrological model Soil and Water Assessment Tool (SWAT) and remote sensing data to detect the LU/LC change- to estimate the runoff, is widely used. It is a agro-hydrological watershed scale model and is compatible for learning the large-scale impacts of LU/LC changes on runoff characteristics.

It requires parameters such as rainfall, temperature, LU/LC map, soil map and a Digital Elevation Model (DEM). Several researchers have applied SWAT model and concluded that it is among the best hydrological models for the simulation of runoff due to change in LU/LC (Carsten, 2000; Hundecha et al., 2004; McColl and Aggett, 2007; Savary et al., 2009; Githui, 2009; Ma et al., 2009; Pakorn et.al., 2010; Hibbard et al., 2010; Berezowski et al., 2012; Fox, 2012; Wijesekara et al., 2012; Shang et al., 2019; Li et al., 2018; Shao et al., 2018; Samie 2019; Shang et al., 2019). Several Indian River catchments were studied the catchment response in terms of streamflow to change in LU/LC by application of SWAT model (Santhosh and Ramesh, 2015; Sajikumar and Remya, 2015; Dwarakish and Ganasri, 2015; Sananda et al., 2017; Sinha and Eldho, 2018; Amogh and Mahesha, 2018).

Land-use/land-cover (LU/LC) changes are mostly in unstable equilibrium and extremely dynamic. The quantification of the effect of this LU/LC changes on streamflow estimation is one of the interesting areas of research in hydrology in the recent past. Since the information of streamflow is required for watershed monitoring, management and development. Many studies were conducted in this area (Hundecha et al., 2004; McColl and Aggett, 2007; Savary et al., 2009; Sajikumar and Remya, 2015). Kristian studied catchment runoff in the semiarid zone of Zimbabwe to ascertain and assess long term effects of land use change and observed that there is a decrease in annual runoff due to intensive agricultural activities (Kristian, 1998).

The increase in sealed surfaces and increased urbanization leads to increase in peak runoff and also effect of summer storms on peak flow is higher than peak flow produced by winter rainfall. A group researchers simulated the effect of land use on surface runoff in the catchment using SWAT model, for both positive and negative land use scenarios (Carsten, 2000; Hundecha et al., 2004). Streamflow was simulated successfully using the model and it was found that there was increase in runoff when existing

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forest and rangeland have been converted into cultivated land.

Studies carried out by all these authors confirm the role of remote sensing in detecting the changes in LU/LC more efficiently and systematically and use the same as among the inputs in the SWAT model. A group researchers carried out the study to assess the response of the hydrologic process to LU/LC change and climate change, using the SWAT model, and concluded that LU/LC is a driving factor in the energy balance within the hydrologic cycle (Ma et al., 2009). Large changes in different land covers have a great effect on the hydrological behavior of catchment, for example, Surface runoff increases as the forest cover decreases (Coutu et al., 2007; Savary et al., 2009; Berezowski et al., 2012).

SWAT model is appropriate for studying the influences of changes in the land use in a greater scale, on runoff characteristics. The inputs needed are: rainfall data, temperature data, LU/LC map, soil map and a DEM. The SWAT model was considered among the best hydrological models for the simulation of runoff due to change in LU/LC by several researchers (Santhosh and Ramesh, 2015; McColl and Aggett, 2007; Shang et.al., 2019; Wijesekara et al., 2012). Investigators have studied the association between climate, land use and hydrological processes, to understand the existing hydrologic system (Nandakumar and Mein, 1997; Bormann et al., 2009; Tang et al., 2011).

The present study has been taken up to assess one of the distinctive west-flowing rivers of Karnataka, India, Netravathi river catchment's response to changes in LU/LC, by considering the remotely sensed data over a period of 35 years. Accordingly, the objective of the present study was framed as to estimate the impact of LU/LCchanges on runoff characteristics in the study area. The present study has been taken up for the Netravati river, one of the distinctive west-flowing rivers of Karnataka, India. It is attempted to find river catchment's response to changes in LU/LC, by considering the remotely sensed data over a period of 35 years.

2. Study Area

The Netravathi River catchment with an area of 3217.81 km^2 along the Western Ghat in Karnataka State, is considered as the study area. The study area is covered between 12°29´45" North & 13°11´00" North latitudes and 74°48´30" East & 75°45´0" East longitudes (Figure.1). River Netravathi originates at Gangamoola of Belladarayana Durga, in the Western Ghats flows westward over a length of 103 Km with its main tributaries Gundia hole, Kumaradhara and Shisia hole, and joins the Arabian Sea at Mangaluru. The altitude varies from 20 m at Bantwal gauging station to about 1000 m above MSL at the origin. More than 90% rainfall occurs during southwest monsoon which lasts between June to September, resulting in the average annual rainfall of 3500 mm (Dwarakish and Ganasri, 2015). The recorded maximum temperature during May and the minimum temperature during December in the catchment area are 38°C and 17°C respectively.

More than 60% of the study area is covered by evergreen, the semi-evergreen and moist deciduous forest along with shrubs form the main vegetative cover in the high land and midland. The major crops include rubber, areca nut, coconut, banana, cashew, paddy, mangrove and vegetables. There are three soil series in the catchment area (HWSD, FAO, 2012). Due to population pressure and industrialization in the Dakshina Kannada (D.K.) district of Karnataka state, the study area is experiencing rapid change in LU/LC, in addition to degradation of forest cover, which leads to soil erosion, which in turn reduces the carrying capacity of the Netravathi river. This change in LU/LC details forms the main input to the SWAT model.

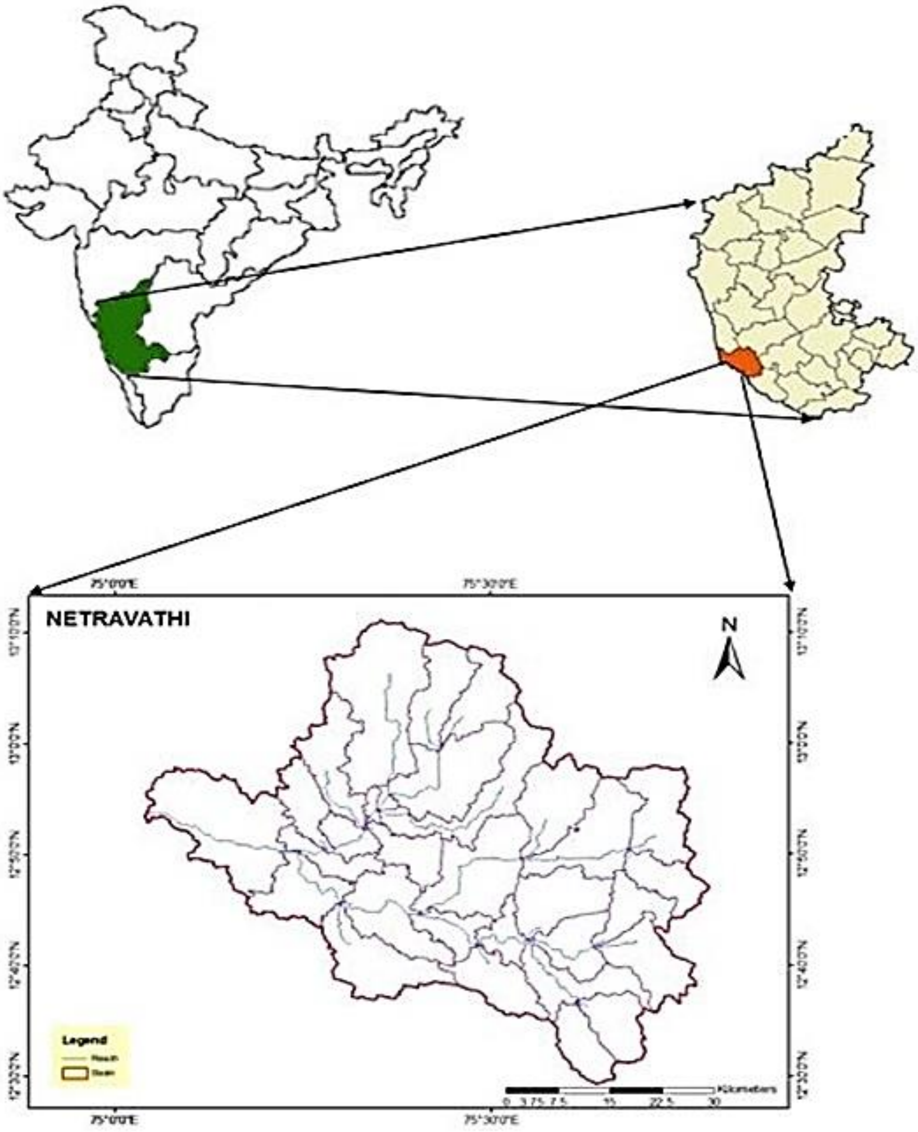

Figure 1: Location Map of Study Area

3. Materials and Methodology

3.1 Data products and software (model)

The various data products used in the present study are shown in Table 1.

Table 1: Data used for the present study

Sl No	Data type	Source	Scale/resolution	Purpose
1	Conventional data	SOI Toposheet No.48K, L, O, and P	1:50000	Base map preparation
2	Remote sensing data	Landsat1-5 MSS & Landsat 4-5 TM data(cloud free data of December, January and February months of 1981, 1991, 2003 and 2015)	60 m and 30 m	Preparing LU/LC Map
	Digital Elevation Model	www.earthexplorer.usgs.gov from ASTER	30 m resolution	Preparing Slope map, and as an input to the SWAT model
3	Rainfall data	IMD rainfall data of 5 Rain gauge stations		Input to the SWAT Model
4	Soil Data	Food and Agriculture Organization (FAO)	5X5 km	
5	Streamflow data and temperature for one gauge station (Bantwal)	www.India-wris.nrsc.gov.in		For validation of the SWAT model

For the present work, both conventional and remote sensing data were used. Conventional data includes Survey of India Toposheet No. 48K, L, O and P, of 1: 50000 scale. Remote sensing data include Landsat1-5 Multispectral Scanning Sensor (MSS) & Landsat 4-5 Thematic Mapper (TM) data, which is cloud free, acquired in the month of December, January and February, 1981, 1991, 2003 and 2015(60m and 30 m resolution). ASTER data was used for Digital Elevation Model (DEM), of 30m resolution. Also, the rainfall data from five raingauge stations of Indian Meteorological Department (IMD), soil data from Food and Agricultural Organisation (FAO), of 5X5 km resolution and stream flow and temperature data from only one available gauging station (i.e. Bantwal station) -were made use of.

3.2 Methodology

Hydrological modeling of the Netravathi river basin was conducted by making use of satellite data, the ARCSWAT and SWAT Cup interface, in ArcGIS environment. Main input required for SWAT includes details of LU/LC, Soil, Slope, DEM and climate data.

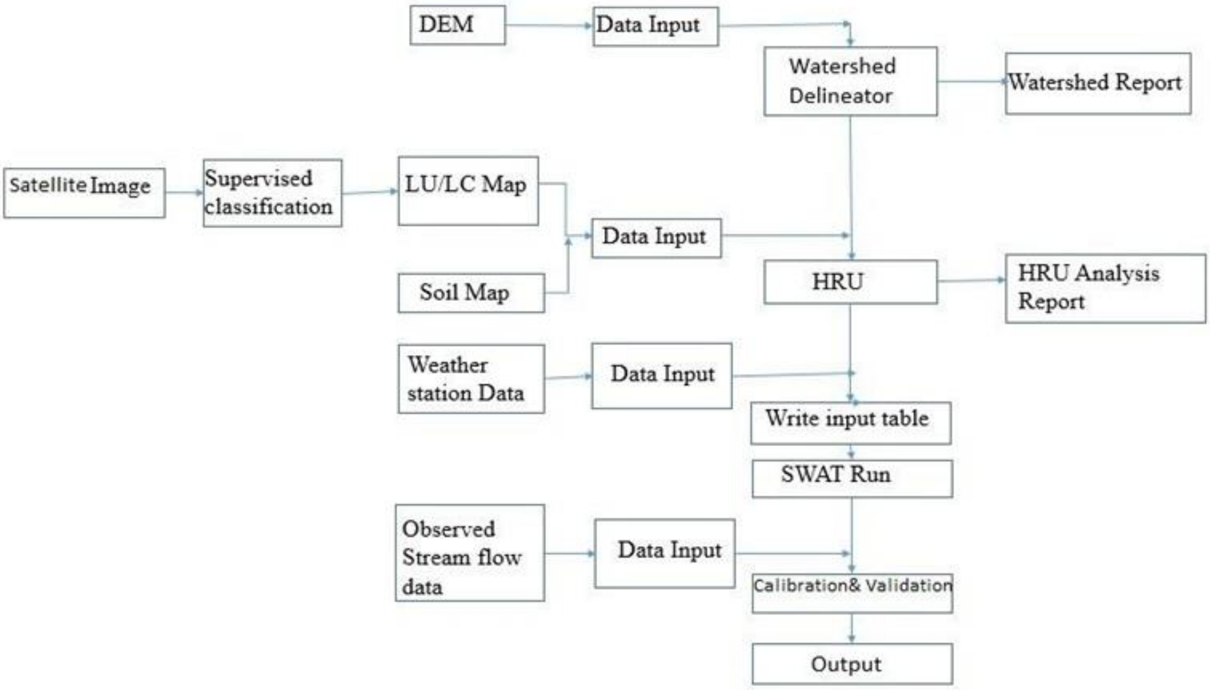

Figure 2: Flowchart for the methodology

Table 2: Climate data for the present study

Sl. No.	Climate Stations	Types of data	Latitude	Longitude	Elevation (m)
1	Bantwal	Rainfall	12° 53’ 16.28” N	75° 01’ 30.02” E	25
2	Belthangadi	Rainfall	12° 59’ 1.19” N	75° 16’ 13.62” E	104
3	Dharmastala	Rainfall	12° 57’ 20.07” N	75° 22’ 46.26” E	104
4	Puttur	Rainfall	12° 46’ 15.29” N	75° 12’ 24.39” E	99
5	Subramanya	Rainfall	12° 40’10.20” N	75° 36’ 38.48” E	136
6	Bajpe	Rainfall	12° 57’ 44.67” N	74° 52’ 47.83” E	26
7	Bantwal	Daily streamflow data	12° 53’16.28” N	74° 01’ 30.02” E	25

3.3 Land Use/ Land Cover [LU/LC]

The maximum likelihood algorithm of supervised classification technique was adopted using the digital image processing software, ERDAS Imagine 10.1. Remotely sensed data were registered with a base map prepared using Survey of India toposheet and pre-processed. Ten prominent training sites were selected, and then statistical analysis was carried out for training sites and verified with high-resolution images from Google Earth. After finalizing the training sites, based on RMSE values, the next step was the selection of the classification algorithm. All the three most frequently used classification algorithm namely maximum likely hood (MLC), parallelepiped (P) and minimum distance to mean (MDM) were applied to 2015 satellite data and based on the final results, MLC algorithm was selected and applied for the remaining data sets to derive and to identify the changes in LU/LC of Netravathi basin.

Since 10 training sites were created, the output LU/LC map was also having only 10 major LU/LC classes. Accuracy assessment was carried out by preparing an error of commission and error of omission error matrix, and then the accuracy on the basis of user's, producer's, overall classification and KAPPA statistics for all the selected remotely sensed data set between 1981 and 2015 were estimated. Finally, post-classification processing was carried out using tools such as re-coding to make the classification more accurate. The overall accuracy (in percentage) and KAPPA statistics for classified images were 81.17 & 0.7908, 85.93 & 0.8438, 86.12 & 0.8468 and 88.67 & 0.8741, respectively for the years 1981, 1991, 2003 and 2015. Finally, these classified images were used as LU/LC maps, among the inputs to run the SWAT model (Figure 3-6).

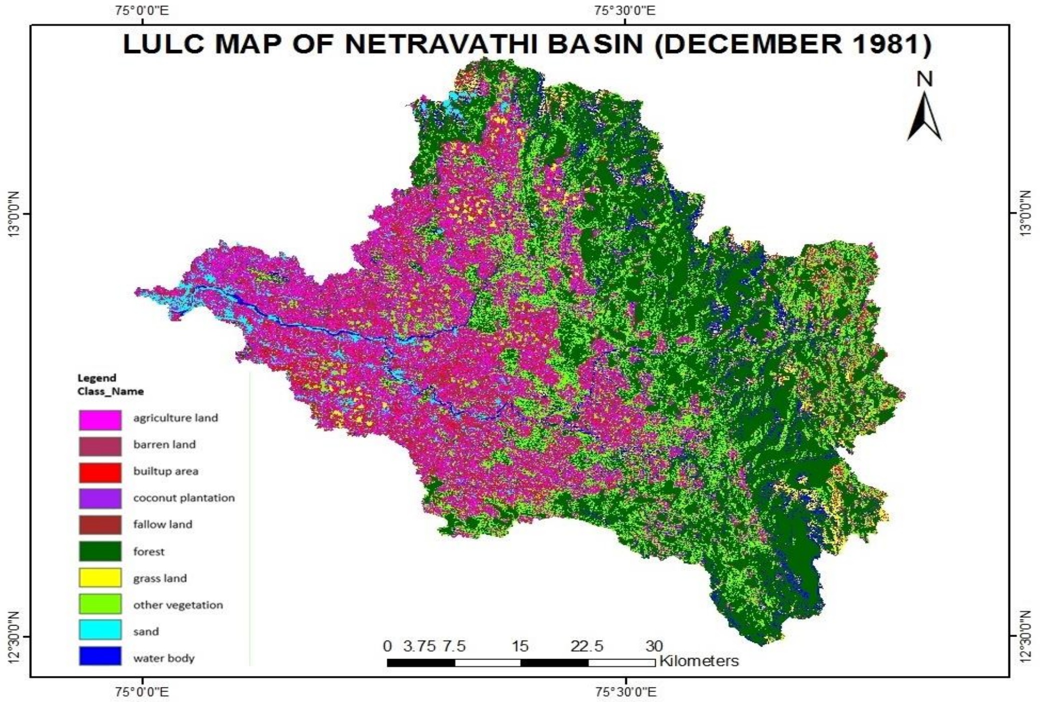

Figure 3: LU/LC map of Netravathi basin for the year 1981

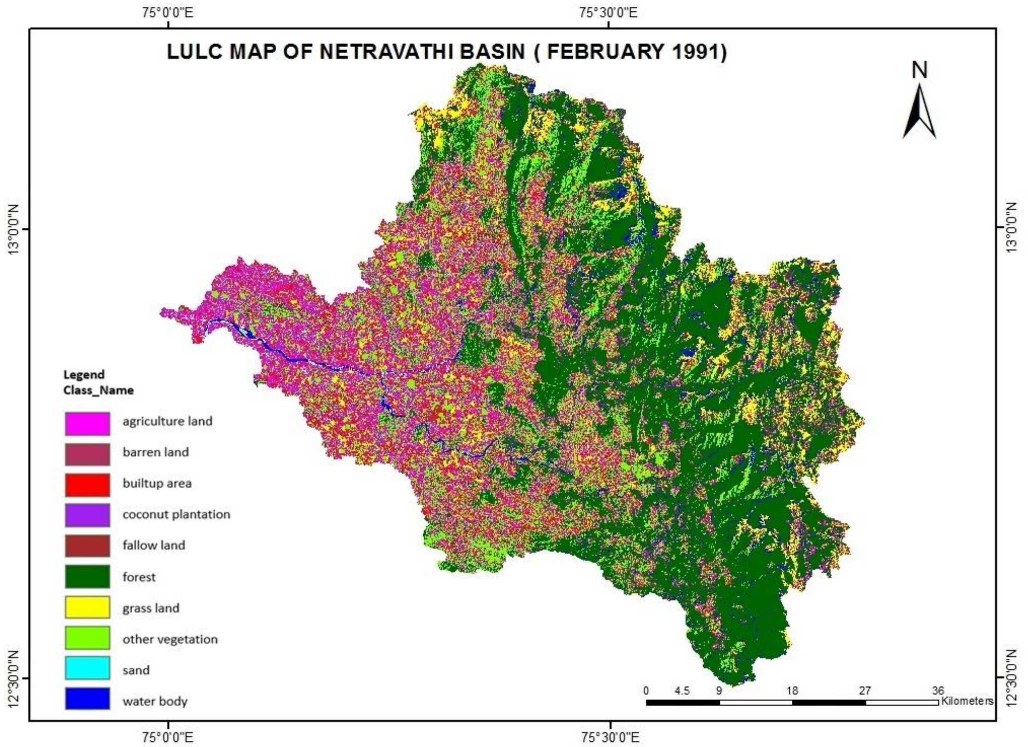

Figure 4: LU/LC map of Netravathi basin for the year 1991

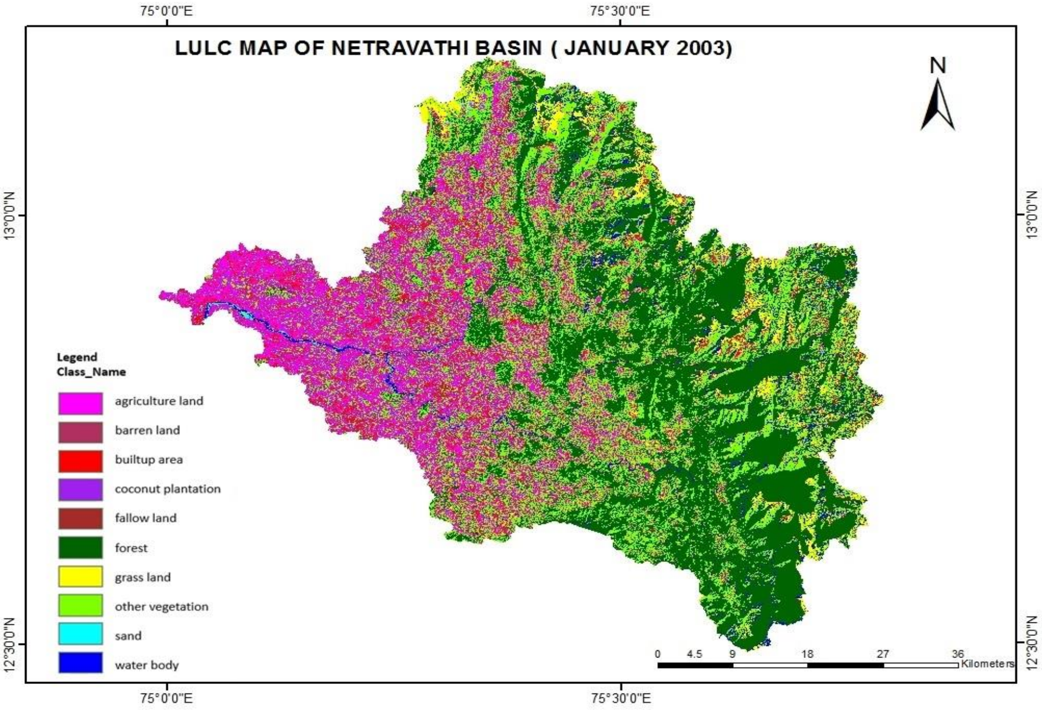

Figure 5: LU/LC map of Netravathi basin for the year 2003

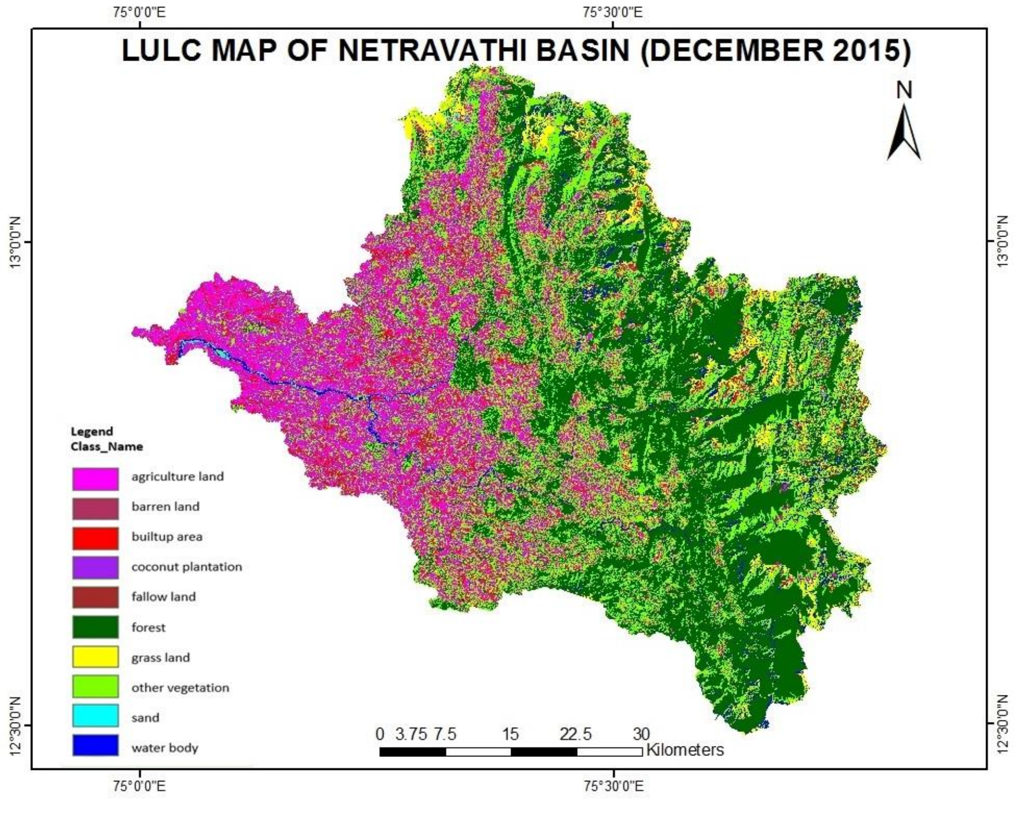

Figure 6: LU/LC map of Netravathi basin for the year 2015

3.4 The SWAT model

The development of hydrological modeling of the Netravathi river basin was conducted using SWAT- a conceptually based, continuous, daily time-step hydrological model, which is semi-distributed, coupled with ArcGIS. The SWAT model is used worldwide for assessing streamflow.

Runoff simulation using SWAT was carried out in four steps, namely watershed delineation, dividing the watershed into Hydrological Response Units (HRUs), feeding all the input to the model and running the model. The governing five phases of model run in a hydrologic process are: 1) Precipitation, 2) Surface runoff, 3) Soil & root zone infiltration, 4) Evapotranspiration & soil, and 5) Snow evaporation & groundwater flow (Babar and Ramesh, 2015). DEM was used to delineate the watershed based on flow direction and accumulation of water, into 33 sub-basins. Further, these sub-basins were divided into a number of HRUs by combining uniquely the LU/LC, soil classes and slope characteristics. The use of sub-basins in a simulation is beneficial when various areas of the watershed are driven by Land Use or Soil layers, to impact hydrology (Neitsch et al., 2002).

Further, the land use, soil and slope grids were overlaid. According to SWAT, there are two divisions of hydrologic cycle: land phase and routing phase. The phase which is tracking the movement of water from the land to the main channel is called the Land phase and on the other hand, the routing phase outlines the water transported through the channel network. Hydrological components of SWAT consist of canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. A daily water budget in each HRU was determined on the basis of the daily components of the hydrologic cycle (Newitsch et al., 2002).

The hydrologic cycle is simulated by the SWAT model on the basis of the following water balance equation.

$$SW_t = SW_o + \sum_{t=1}^{t}(R_t - Q_t - ET_t - P_t - QR_t) \quad (1)$$

Where SW_o and SW_t are the soil moisture content at the initial and at the end of a time duration for which the water balance equation is written in millimeter unit. R_t, Q_t, ET_t, P_t and QR_t are, namely, the rainfall, surface runoff, evapotranspiration, percolation and lateral flow respectively.

Nash Sutcliffe Efficiency (NSE) and coefficient of determination (R^2) are two parameters which will be commonly used in any hydrologic modelling to check the calibration/validation, especially when limited measured data are available. If the value of NSE is between 0 and 1, indicates the deviation of measured and predicted values. If NSE is negative, it indicates the predictions are poor.

4. Results and Discussion

The main purpose of the present work was to identify the effect of change in LU/LC on Netravathi river basin streamflow, in Karnataka. For this reason, LU/LC information was obtained through remotely sensed data coupled with hydrological model SWAT. Remote sensing data of 1981, 1991, 2003 and 2015 were classified and 10 LU/LC classes were identified. They are agricultural land, barren land, built-up area, coconut plantation, fallow land, forest, grassland, other vegetation, sand and water body.

Table 3: Percentage change in LU/LC classes

Sl No	LU/LC classes	1981	1991	% change	2003	% change 1991-2003	2015	% change 2003-2015	% change 1981-2015
1	Agriculture land	10.33	11.22	8.62	14.09	25.58	15.16	7.59	46.76
2	Barren Land	3.12	2.39	-23.40	2.2	-7.95	2.13	-3.18	-31.73
3	Built up area	2	2.94	47.00	4.14	352.80	6.23	50.48	211.50
4	Coconut plantation	3.2	5.58	74.38	7.02	25.81	7.13	1.57	122.81
5	Fallow land	2.06	1.66	-19.42	1.31	-21.08	1.2	-8.40	-41.75
6	Forest	43.78	42.91	-1.99	38.53	-10.21	36.48	-5.32	-16.67
7	Grass land	2.38	3.03	27.31	3.37	11.22	3.42	1.48	43.70
8	Other vegetation	27.35	25.59	-6.44	24.16	-5.59	23.07	-4.51	-15.65
9	Sand	1.26	0.85	-32.54	1.59	87.06	1.64	3.14	30.16
10	Water body	4.52	3.83	-15.27	3.59	-6.27	3.54	-1.39	-21.68

4.1 Effect of LU/LC on Streamflow

LU/LC maps for the years 1981,1991,2003 and 2015 are shown in Figures 3 to 6 and the corresponding areal extent of all the 10 LU/LC is given in Table 3. From figures 3 and 4, and Table 3, it is clear that between 1981 and 1991, agricultural land, built-up area and coconut plantation has been increased by 8.6%, 47% and 74.37% respectively. The total change from 1981 to 2015 in agricultural land, built-up land and coconut plantation are 46.76, 211.5 and 122.81. The information about LU/LC is among the input parameters of the SWAT model. However, while running the SWAT model, remotely sensed images were reclassified into six primary classes, namely Agriculture land, Built-Up area, Forest, Coconut plantation, Other vegetation and Others, since SWAT model considers only six LU/LC classes and this information is available in SWAT access table. The complete watershed is further delineated into 33 sub-basins (Figure 10) using the drainage map (Figure 9) and DEM (Figure 8).

4.2 Soil Map

The soil map for the study area was developed from the Harmonized World Soil Database (HWSD) provided by the Food and Agriculture Organization at a spatial resolution of 5x5 km. There were three soil classes (series) for the study area (FAO 2012).

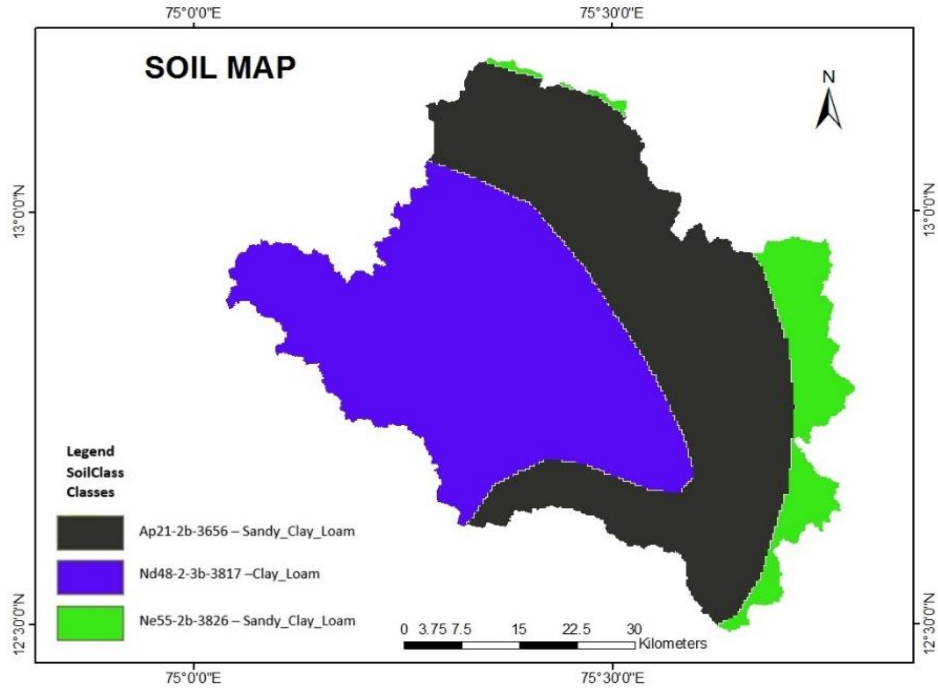

Figure 7: FAO Soil Map of the study area

4.3 Digital Elevation Model Map

The digital elevation data for the present study was acquired from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with a ground resolution of 30 m. This data was pre-processed and Digital Elevation Model (DEM) was created (Figure 8). DEM was used to derive the parameters at sub-basin level, for instance channel length, width and slope, and used as input data for the SWAT model.

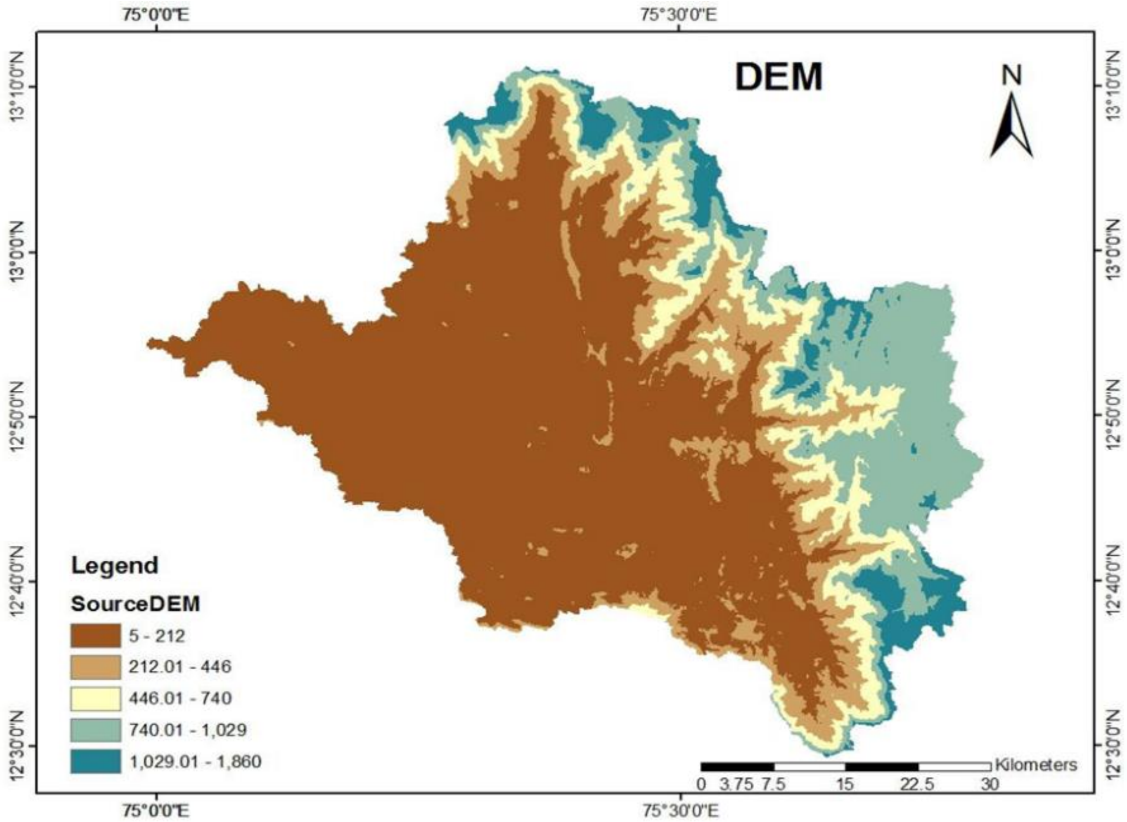

Figure 8: Digital Elevation Model of the study area

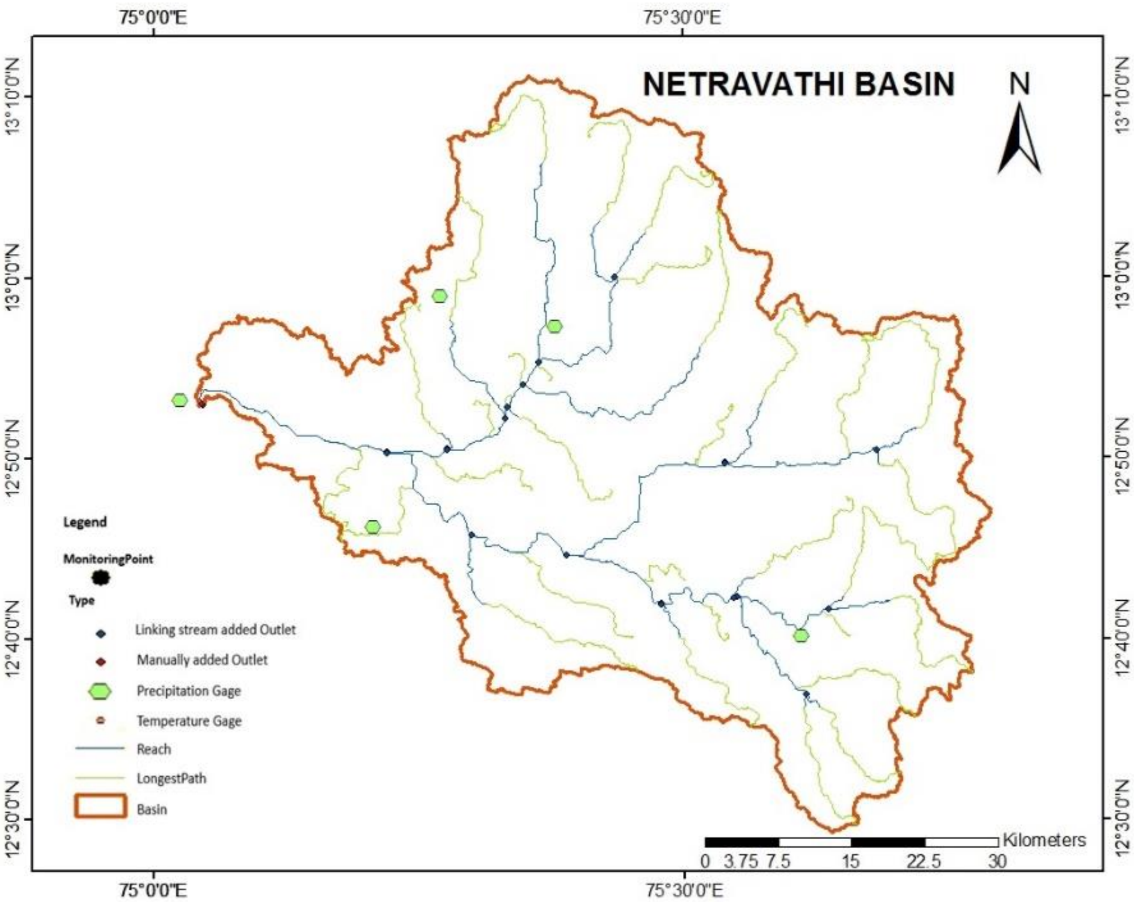

Figure 9: Drainage Map

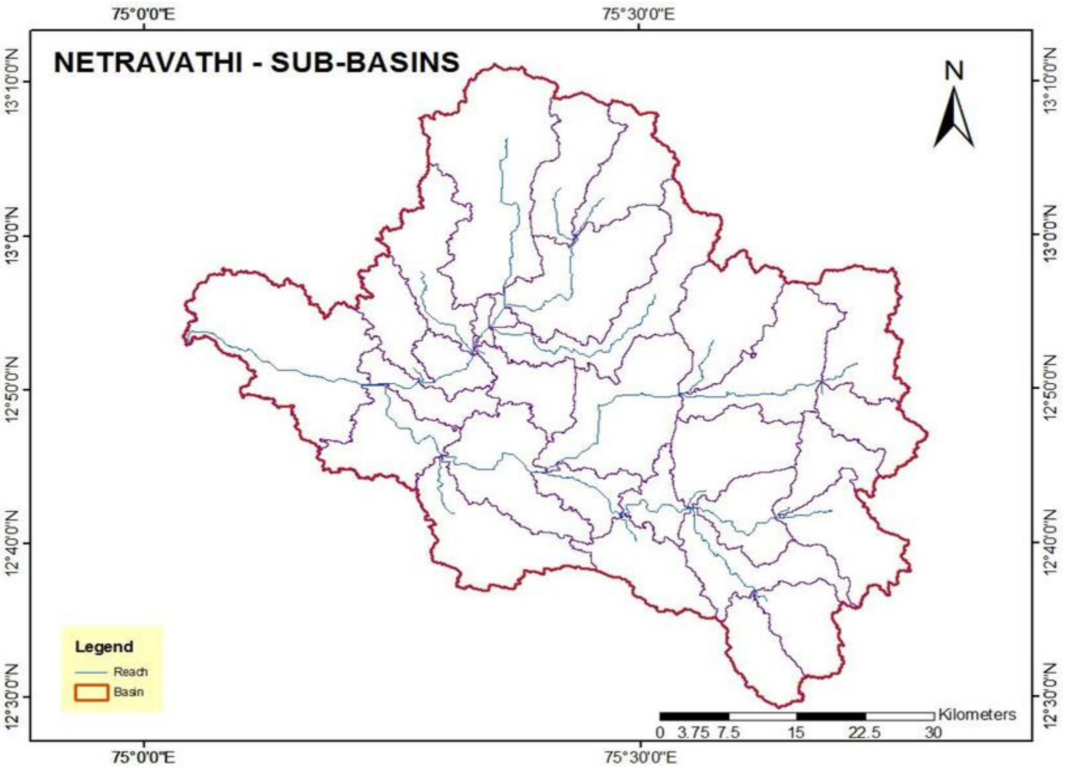

Figure 10: Netravathi Sub-basin

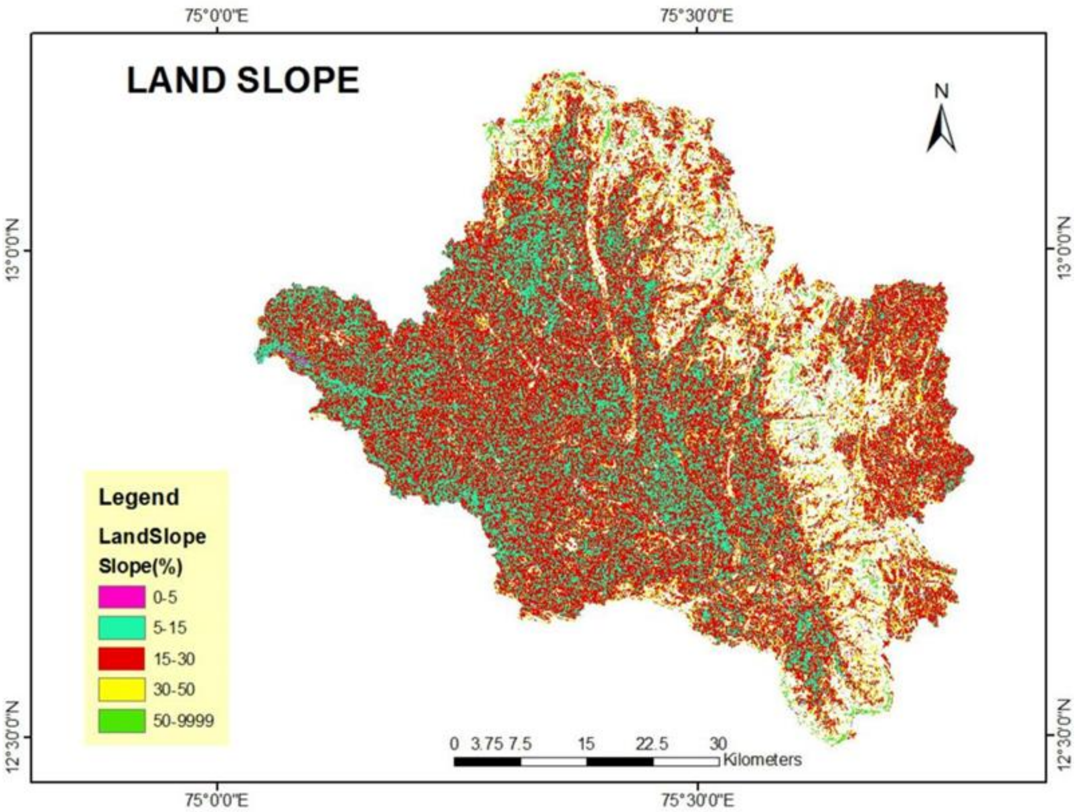

Figure 11: Slope map

4.4 Calibration and validation of SWAT model

Calibration of the SWAT model parameters was carried out by applying sequential uncertainty fitting (SUFI – 2) method (Abbaspour et al., 2004; Shao et al., 2018). The SUFI -2 method is the combination of optimization and uncertainty analysis to adopt a global search procedure. In the present study, the performance of the model was estimated by the application of coefficient of determination (R^2) and the Nash Sutcliffe Efficiency (NSE).

The analysis has been grouped into 3 phases, namely the first phase (1981-1986) , for calibration and 1987-1990, for validation; second phase (1991-1996) for calibration and 1997-2000, for validation; and the third phase (2001-2006), for calibration and 2007-2010, for validation. Both calibration and validation of the model was done for the available data in each phase. Streamflow data of Bantwal station, around 25 km upstream of Mangaluru city was collected from the WRIS website (www.India-wris.nrsc.gov.in). In the Ist and IInd phase data from 1981- 1986 and 1991-1996, and 2001-2006, was employed for calibration and from 1987-1990, 1997-2000 and 2007- 2010, is made use for validation of the model. The scatter plots for the calibration and validation period for the three phases are shown in figure12 to figure 17. The time series plot for the validation phase is shown in figure 14.

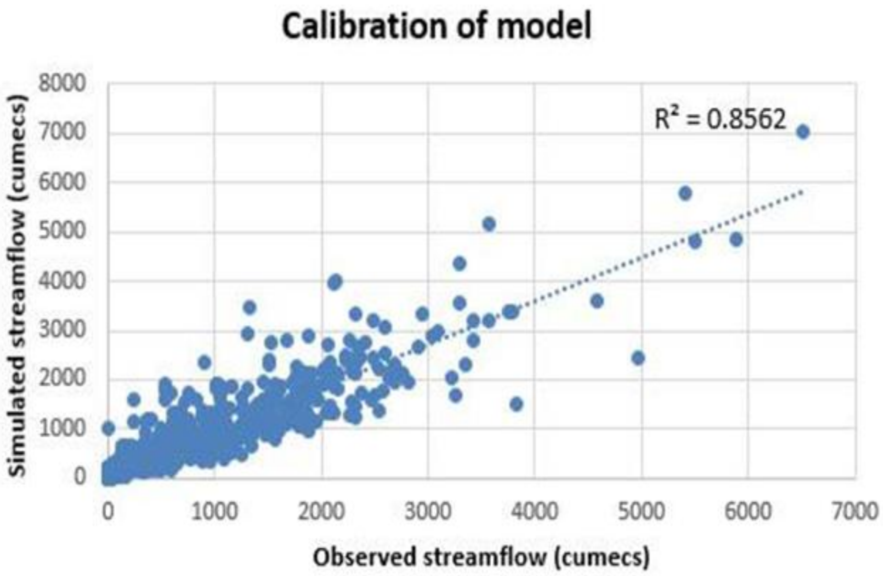

Figure 12: Simulated v/s observed streamflow for calibration (1981-1986)

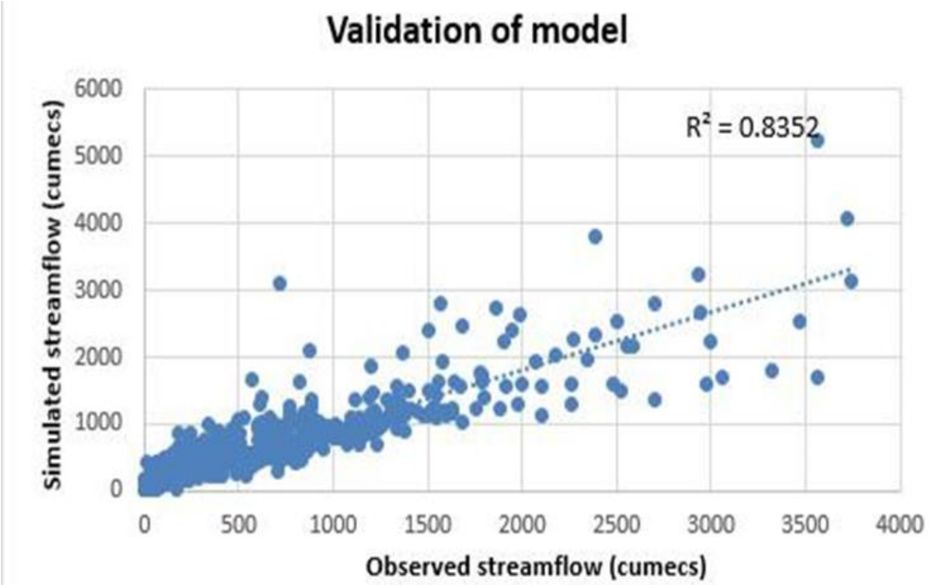

Figure 13: Validation: Simulated v/s observed streamflow (1987-1990)

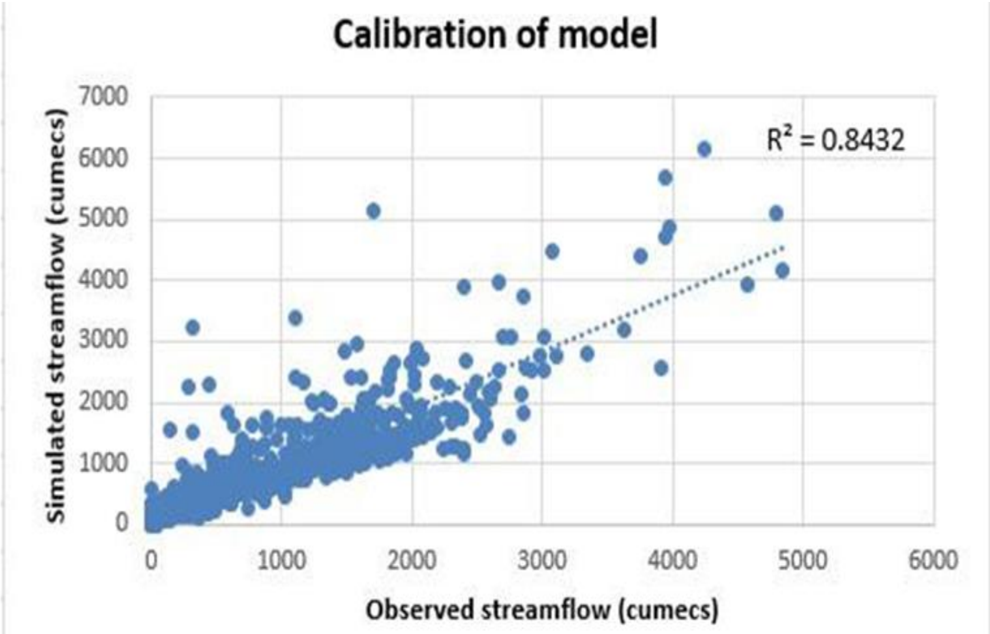

Figure 14: Simulated v/s observed streamflow for calibration (1991-1996)

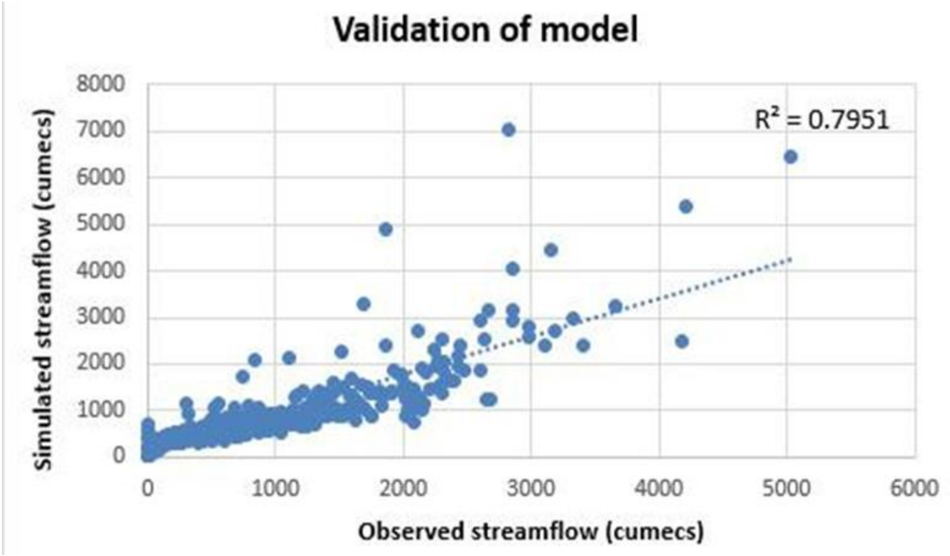

Figure 15: Simulated v/s observed streamflow for validation (1997-2000)

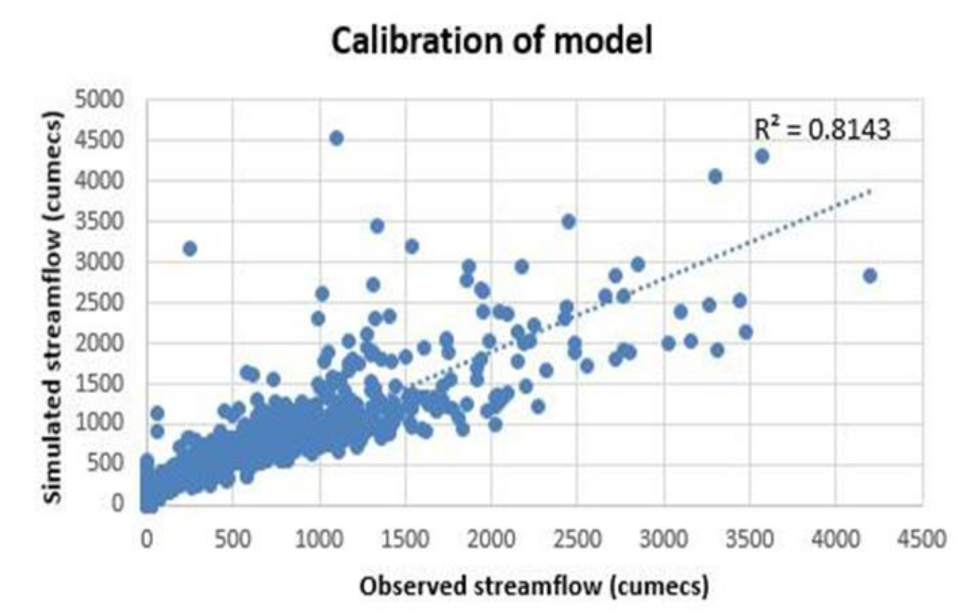

Figure 16: Simulated v/s observed streamflow for calibration (2001-2006)

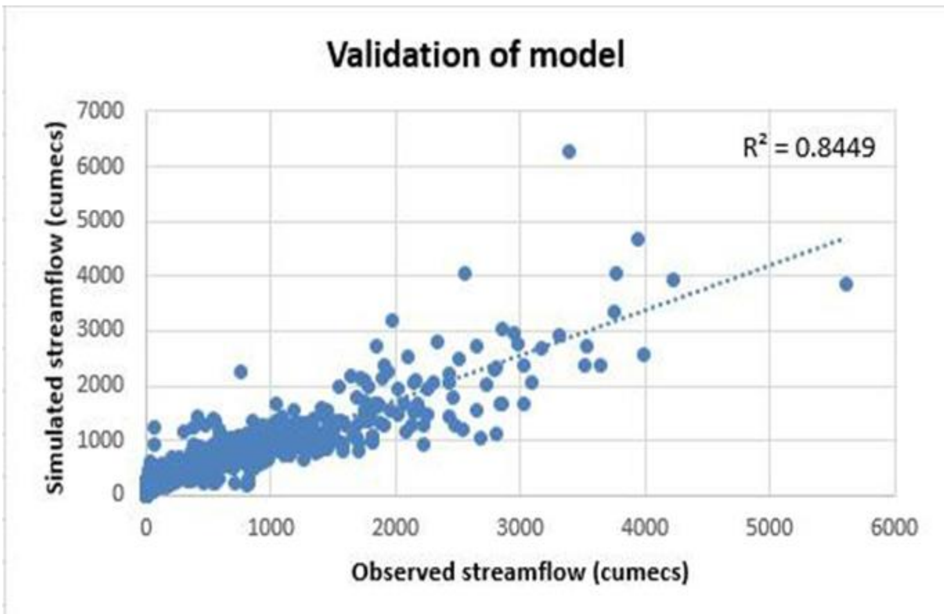

Figure 16: Simulated v/s observed streamflow for validation (2007-2010)

Table 4: Calibration and Validation of the SWAT model

	Calibration			Validation		
	I	II	III	I	II	III
R^2	0.86	0.84	0.81	0.84	0.80	0.84
NS	0.85	0.83	0.78	0.83	0.78	0.84

From the scattered plots, it can be seen that R^2 value is more than 0.80 for all the three phases, indicating a good correlation between estimated/modelled streamflow and observed streamflow. In addition to this, the NSE value is more than 0.75 both for calibration as well as validation of the model in all the three phases. Streamflow simulation is satisfactory, if 0.7 < NSE < 0.8 and 0.75 < R^2 < 0.85 (Moriasi et. al. 2015, Shao et. al. 2018). In the present study, final results are satisfying the above criteria and hence, justifying the efficiency of the SWAT model and its applicability to estimate streamflow in the Netravathi basin.

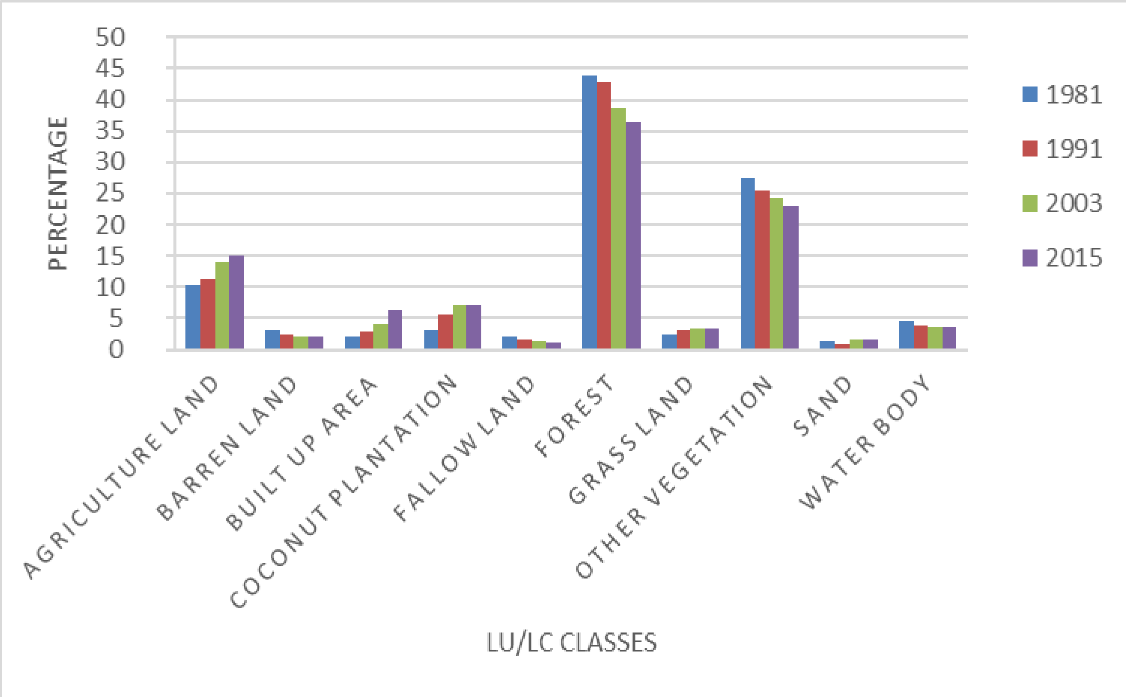

Figure 17: LU/LC change

4.5 Effect of change in LU/LC on streamflow

The bar chart showing the percentage change of all the 10 LU/LC classes and for all the three phases are shown in Figure 15. From the bar chart, it is clear that the percentage forest area and other vegetation cover areas decreased from 43.78 to 36.4 and from 27.35to 23.07respectively. On the other hand, the built-up area increased by 4.23% (i.e. 2 to 6.23) and coconut plantation also increased by 4.11 (i.e. 3.2 to 7.13), over a period of 30years (Table 5). (Sinha and Eldho, 2018; Jose and Dwarakish, 2020; Ganasri and Ramesh, 2015).

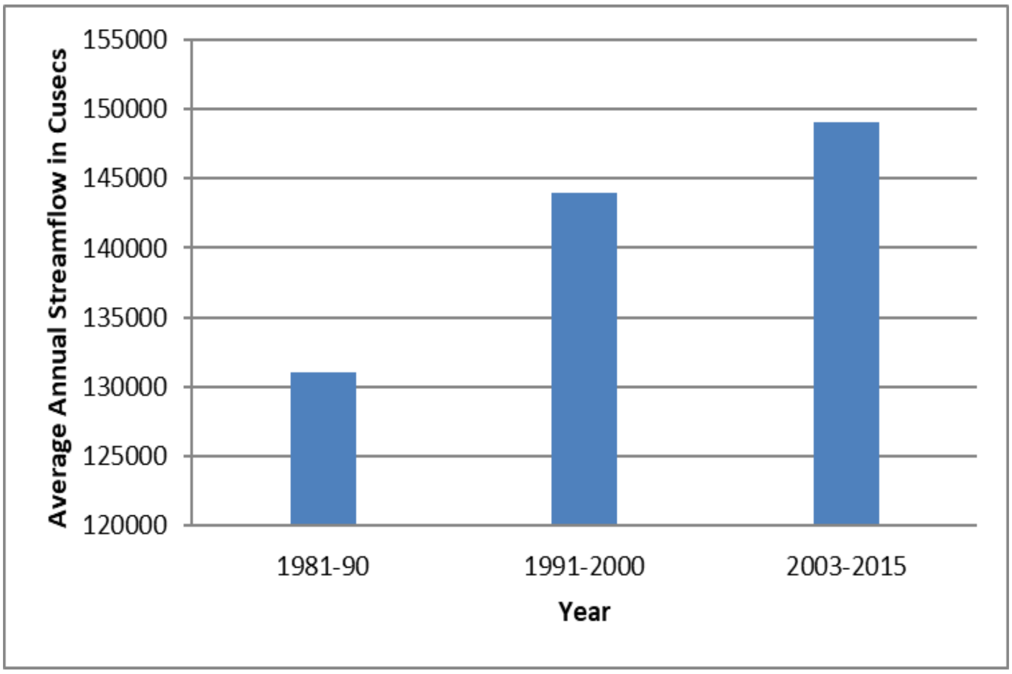

Figure 18: Annual average discharge

The average annual streamflow for all three phases (from SWAT analysis) is shown in figure 16. The annual streamflow during 1981-1990, 1991-2000 and 2003-2015 is 131000, 144000 and 149000 cusecs respectively. This shows that there is an increase of 13.74% in streamflow over a period of 30 years, and this is mainly attributed to change in Land Use/Land Cover in the Netravathi river basin. Hence, it can be concluded that LU/LC changes in the catchment have a direct impact on the runoff of the catchment. Further, the performance of the SWAT hydrologic model is satisfactory as far as the Netravathi river catchment is conerned.

Table 5: LU/C classes recalculated for SWAT

Sl No.	LU/LC classes	1981(area in %)	1991(area in %)	% change 1981-1991	2003(area in %)	% change 1991-2003	2015(area in %)	% change 2003-2015	% change 1981-2015
1	Agriculture land	10.33	11.22	8.62	14.09	20.37	15.16	7.06	31.86
2	Built Up area	2.00	2.94	47.00	4.14	28.99	6.23	33.55	67.90
3	Forest	43.78	42.91	-1.99	38.53	-11.37	36.48	-5.62	-20.01
4	Coconut plantation	3.20	5.58	74.38	7.02	20.51	7.13	1.54	55.12
5	Other vegetation	27.35	25.59	-6.44	24.16	-5.92	23.07	-4.72	-18.55
6	Others	13.34	11.76	-11.84	12.06	2.49	11.93	-1.09	-11.82

5. Conclusions

The current study was carried out to estimate the impact of LU/LCchanges on runoff characteristics of the Netravathi river basin, Karnataka, India, using the SWAT model. To estimate the effect of LU/LC changes on streamflow, LU/LC maps of 1981,1991, 2003 and 2015 were employed, and based on the present study the following conclusions were drawn:

The important changes in the LU/LC from 1981 to 2015 includes agricultural land (31.86%), built-up area (67.90%), forest cover (-20.01%), coconut plantation (55.12%), Other vegetation (-18.55%) and Others (-11.82%).

The value of $R^2 > 0.8$ and NSE > 0.78 indicates the satisfactory performance of the SWAT model. Hence, SWAT hydrologic model can be effectively used to estimate runoff in the Netravathi river basin.

The average streamflow is increased by 13.74% from 1981 to 2015, which is mainly due to dynamic changes in LU/LC. Hence, it can also be concluded that changes in LU/LC have a direct impact on streamflow in the study area.

The current study was carried out to estimate the impact of LU/LCchanges on runoff characteristics of the Netravathi river basin, Karnataka, India, using the SWAT model. To estimate the effect of LU/LC changes on streamflow, LU/LC maps of 1981,1991, 2003 and 2015 were employed, and based on the present study, it has been concluded that there is an increase in agricultural land, built up area and coconut plantation, and decrese in forest cover and other vegetation, which is an indication of change in the land use pattern, as per the previous study found in the literature. The SWAT model resuls show that the model can be efficiently used to estimate the runoff, for west flowing rivers, of Karnataka, India. Streamflow data of the study area has revealed the clear relation between the LULC and streamflow. Further, the validation of the model using the in-situ data from only one available station, i.e., Bantwal, has also supported the results, as per the published literature. The major outcome of the study is that the model can be effectively used even for a river joining sea and the area has been considered for the first time.

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