LAND USE LAND CHANGE IMPACT ON HYDROLOGY OF THE FOREST WATERSHED, INDIA

Nagaveni Chokkavarapu*
and
Pavan Kumar K **

ABSTRACT

Land use change is the main factor influencing watershed hydrology and could serve for developing better watershed management practices. The behaviour of each process in hydrology is influenced by its attributes and other processes. Present study analyses the impact of land use change on watershed hydrology in Nallamala forest watershed, India. The Soil and Water Assessment Tool (SWAT) is used to simulate runoff using different land use land cover (LULC) maps of 2000 and 2010. In present study land use changes and hydrological responses were quantified to investigate the runoff responses on annual basis time scale using SWAT to study the impacts of land use land cover change. A calibrated SWAT model simulated annual runoff processes for a period of 10 years i.e. 2000 to 2010. Sensitivity analysis for input parameters is analysed using the SUFI-2 algorithm in SWAT_CUP (Calibration Uncertainty Programme). Four SWAT input parameters are more sensitive including CN2.mgt, Delay.gw, sol_awc.sol and sol_k.sol. Hydrological model could simulate runoff for each sub-basin using two land use scenarios 2000 and 2010, soil map and DEM. It is observed that model results using optimised parameters, hydrological processes are better predicted with statistical evaluation methods like Nash-Sutcliffe Efficiency(NSE) and Coefficient of determination(R^2). The results from present study help to quantify the potential impacts of land use land cover (LULC) change on total yield of water within watershed using SWAT model.

Keywords : Land Use Land Change, Hydrological Response, SWAT, Runoff.

* Centre for Disaster Mitigation and Management (CDMM). nagaveni.ch@gmail.com
**Department of Environmental and Water Resource Engineering,
School of Civil and Chemical Engineering, VIT University, Vellore - 632014, TN.

Introduction

Vegetation change acts as a major component in quantifying and interpreting the hydrological response of the land use land cover change. The hydrologic cycle explains total water storage and movement within a watershed. To restore ecological balance and watershed management practices, thorough knowledge of hydrological response to local climate variables and land use land cover change practices are required. In a watershed soil properties can be improved by proper management of land use/land cover practice (Chen et al 2003). Different researchers studied the influence of land use land cover change on hydrological processes like annual mean runoff with the help of hydrological modeling. The sensitivity of runoff differs across watersheds temporally and spatially to the rainfall intensity. A hydrological model helps to predict the impact of land use land cover change on runoff. These models require long time series of data to analyse the land use land cover change impact on surface runoff and soil erosion within the catchment area. Distributed hydrological models are popular to study catchment hydrology. These models need data of input parameters relevant to land cover properties, soil properties, slope and meteorological parameters. Land cover change can cause change in vegetation which can alter flood frequency and extremes (Brath et al, 2006), mean annual discharge (Costa et al,2003) and change in base flow (Wang et al,2006). In watershed hydrology assessment, interactions and relationships between human activities and natural phenomena are important to understand the surface features with the help

of change analysis which improves better resource management and decision making. Change detection involves analysis of surface feature occurrence quantitatively to determine the changes associated with land cover land use with the help of multi-temporal satellite datasets.

In the past fifteen years, Nallamala forest watershed area has significantly experienced conversion of forest from agriculture land including deforestation. These land use changes have affected the hydrological cycle thus increasing rate of runoff and soil erosion. This hilly landscape associated with land cover change and rocky base layers has decreased rate of water infiltration thus raising major environmental concerns. Soil and Water Assessment Tool (SWAT) was developed by U.S. Department of Agriculture (USDA) which has proven to be a promising tool for assessment of hydrology (Arnold et al,1998). SWAT has a wide range of applications to deal with variety of watershed problems (Gassman et al,2007) like impacts of land use land cover changes (Breuer et al,2009). Knowledge about annual and monthly mean runoff, stream discharge and groundwater is important for long-term watershed planning to protect water resources. The relationship between hydrological parameters and land use change are dynamic depending on topography, geology, soil type, climate and land use type (Hernandez et al,2000). Sensitivity analysis provides an opportunity to identify model sensitive parameters to improve model performance and reduce uncertainty. (Arnold et al,1998) used sensitivity analysis to identify sensitive hydrological parameters using SWAT

model in Mississippi river basin. Several studies have been conducted using SWAT to evaluate the impact of land use change on runoff (Githui et al,2009;Li et al,2009;Wang et al,2006).The objective of our study is to investigate the hydrological responses to land use land cover change in semi arid forest watershed using Soil and Water Assessment Tool (SWAT).The SWAT model is an effective model to observe rainfall-runoff relationship under different land use conditions.

Methodology

Study Area : Nallamala watershed area (Figure1) is situated in Telangana State,India. The watershed has an area of 2988 km2 and extends between latitude 15045' to 16045'N and longitude 78025' to 79029'E.The mean elevation of basin is 491m,

from 891mto 1100m. For the period 2000 to 2010 the average annual precipitation was 1103mm. Maximum temperature in summer (April and May) was 390 C and minimum temperature (December and January) was 150 C in winter season. The rocks found here are oldest rocks which have been formed due to volcanic activity. These rocks belong to Kadapa system. The youngest rocks belong to Quartzite and sand stone. The rock surface is impervious to water percolation which accounts for large volume of runoff and stream flow. The Nallamala forest watershed is characterised with deciduous and scrub forest as dominant land cover type. Middle and lower parts are with settlements and agriculture. The climate in this basin is semi arid with seasonal variations.
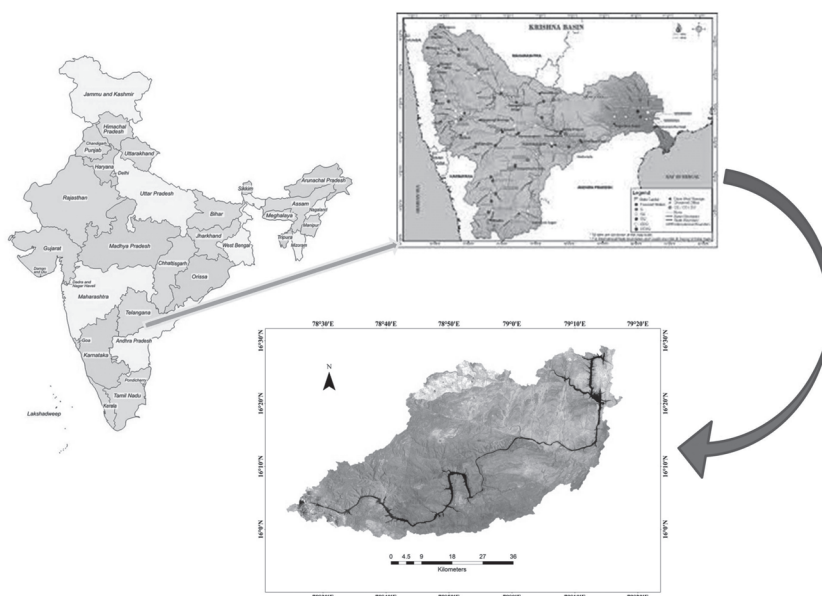

Figure 1: Location of the Nallamala Watershed in India

Soil and Water Assessment Tool (SWAT)

SWAT is a physically distributed hydrological model that is suitable for river basin or catchment scale to investigate the impact of land use practices on water quality, sediment and agriculture chemical yields in large watersheds with spatially distributed different soils, land use land cover (Arnold et al,1998). SWAT is a continuous time series model best suitable to simulate long-term impacts of land use management practices (Neitsch et al,2005). Components of SWAT simulation include weather, hydrology, soil ,plant growth, nutrients, pesticides and land management practices (Gassman et al, 2007). This paper explains the long-term impacts of land use change and spatial variations in rainfall and temperature on the hydrology of the study area.

Water balance equation of SWAT (Equation1):

$$SWt = SWo + \sum_{j=1}^{t}(PREC - SURQ - ET - PERCO - BF) \quad (1)$$

Where,

$SW\,t$ = soil water content (mm), $SW\,o$ = soil water content available for plant uptake, t = time (days), PERC = amount of precipitation, SURQ = amount of surface runoff (mm), ET= amount of evaporation (mm), PERCO = amount of percolation (mm), BF = amount of base flow (mm).

Present study has been divided into the following steps (1) data preparation (2) watershed delineation (3) HRU creation (4) sensitivity analysis (5) calibration and validation.

Data Preparation

SWAT requires data of topography, land use and land cover, soil variables, and meteorological data (Table 1).We have used 30 m SRTM DEM to delineate watershed into sub-basins. Land use land cover maps were generated from Landsat 5 and Landsat 8 images for 2000, 2005 and 2010 years, respectively. The soil map was obtained from National Remote Sensing Agency (NRSA) and soil physical and chemical properties were obtained from National Bureau of Soil Survey (NBSS,Nagpur). Weather data got from Central Water Commission (CWC) and Indian Meteorological Data (IMD).The Landsat 5 TM/ETM and 8 satellite images of Nallamala were acquired for three different years 2000, 2005 and 2010 with 0 per cent cloud cover.

Table 1: List of Variables and Data Sources Used

Variable	Data source
Land use land cover map	Landsat 5 and 8 images
Soil map	National Remote Sensing Agency (NRSA)
Digital Elevation Model	Shuttle Radar Topography Mission (SRTM)
Precipitation,temperature,relative humidity, solar radiation, wind speed	Indian Meteorological Data (IMD)
Runoff data	Central Water Commission (CWC)

Land Use Land Cover Classification : Land-cover change is identified comparing images obtained from Landsat 5 and 8 from 2000 to 2010.Initially these images were classified using supervised classification (maximum likelihood) method using visual interpretation and ground truth. Accuracy assessment was carried using ground control points.The land use land cover classes classified are deciduous forest, scrub forest, agriculture, barren land, and degraded forest and water bodies. The distinction between fallow land and barren land is established based on the annual crops. The performance of classification is assessed using accuracy assessment technique. The multi-temporal imagery helps in finding an area with different LULC a period. According to NRSA, land cover is classified based on the following description given in Table 2.

Table 2 : Different Land Cover Description for Classification

Land Cover	Description
Deciduous forest	Vegetation with a per cent cover <40 per cent .These are composed of species, which shed their leaves once a year, during summer.
Degraded forest	Forest areas where canopy cover/density range between 10-40 per cent.
Scrub forest	These are forest areas with crown density less than 10 per cent of the canopy cover.
Cropland	Lands under farming, production of food, fiber, commercial and horticulture crops.
Built up	Areas with buildings and other man-made structures
Barren land	Rock exposures which are often barren and without vegetation cover
Water	Surface water like ponds, lakes, reservoirs, streams, rivers, canals, etc.

Change Detection : Multi-date satellite images were classified into different classes.The area of each class covered is compared for 2000 and 2010.Change detection of these classified images, gives information about each class in spatial composition (Table 3). Accuracy assessment gives the measurement of quality information from classified satellite images. Overall accuracy is improved by spatial, spectral, geometric and radiometric resolution of satellite data and ground truth information. Selecting training pixels of known land use class improve the spectral characteristics of different land cover classes.

Table 3: Classification Results of 2000 and 2010

Year	Agriculture	Deciduous forest	Scrub forest	Degraded forest	Barren land	Water bodies
			2000			
% area	6.18	49.47	27.9	2.88	9.18	4.26
Area,Km2	185.07	1481.06	835.25	86.25	274.89	127.66
			2010			
% area	15.32	47.22	24.57	2.28	7.15	3.46
Area,Km2	458.13	1412.13	734.84	68.24	213.73	103.43
			Change			
% area	+9.14	-2.25	-3.33	-0.06	-2.03	-0.8
Area,Km2	+273.06	-68.93	-100.41	-18.01	-61.16	-24.23

Accuracy Assessment: Accuracy assessment measures the quality of information obtained from classified satellite images. Error matrices give overall accuracy, users accuracy and producers accuracy (Table 4). Landsat images, ground truth data, visual interpretation support better classification of land use land cover (Giri et al, 2013) from 2000 to 2010. Ground truth helps to improve spectral characteristics of different land use classes to select suitable training pixels.

Table 4: Accuracy Assessment for Land Use Classes

Land use type	Reference totals	Classified totals	Number correct	Producers' accuracy	Users' accuracy
Built up land	13	11	10	76.92%	90.91%
Kharif crop	16	16	15	93.75%	93.75%
Rabi crop	9	10	8	88.89%	80.00%
Double/ triple crop	7	5	4	57.14%	80.00%
Current fallow land	9	8	8	88.89%	100.00%
Deciduous forest	14	14	12	85.75%	88.75%
Barren land	4	5	4	100.00%	80.00%
Scrub forest	5	6	5	100.00%	83.33%
Degraded forest	2	3	2	100.00%	66.67%
Water body	4	4	4	100.00%	100.00%

Watershed Delineation

DEM is used to identify elevation and topographic features of the terrain. In watershed delineation, drainage network is defined and basin is split into sub-basins and the network of channels is calculated. Basin is delineated into 44 sub-basins and stream network (Figure 2) Elevation ranges from 156m to 891m. Three slope classes have been taken to categorise slope across watershed (Table 5).
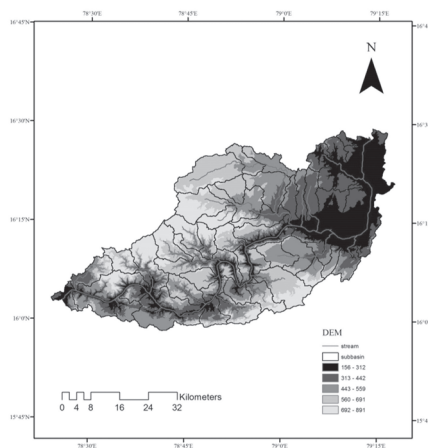
Figure 2: Watershed Delineation

Table 5 : Slope Classes

Slope class	% watershed
0-10.0	58.18
10.0-20.0	18.11
20.0-9999	23.70

Hydrological Response Units (HRU) Generation

HRU is a homogeneous unit which describes different parts of the sub-basin in terms of soil, slope and land use land cover. Each sub-basin is then divided into hydrological response units (HRUs) with a total of 277 HRUs. Different soil types are described in Table 6 and area occupied within the watershed.

Table 6: Soil Type and Area Distribution

Soil name	% watershed
Shallow gravelly red soils	74.10
Gravelly clayey shallow dark brown soils	17.49
Gravelly loamy dark brown moderately deep soils	3.96
Clayey to gravelly clayey moderately deep dark brown soils	0.10
Water bodies	4.30

Weather data used for simulation include daily precipitation, maximum and minimum temperature, solar radiation, relative humidity, and wind speed data. At the HRU level surface runoff, lateral sub-surface flow, evapotranspiration (ET), infiltration, percolation losses, channel routing, sedimentation, nitrogen loss, and agricultural management are simulated. Soil data-base includes attribute data like available water content, saturated hydraulic conductivity, bulk density, and organic matter content. Soil map of the watershed is shown in Figure 3.
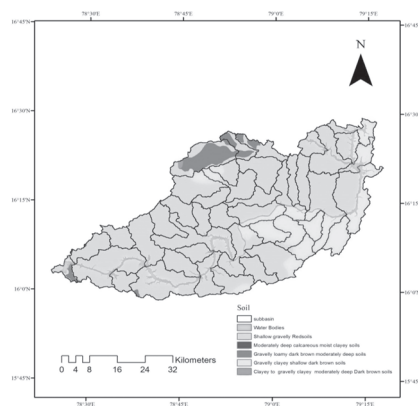

Figure 3: Soil Types in Watershed

Parameter Sensitivity Analysis

Model simulated runoff was compared with observed data on monthly basis. Initially the model was calibrated on monthly basis and model was run between 2003 to 2004 and validation from 2007 to 2009. For model initialisation three years data used as burn in period as the data were available for that period.

Sensitivity analysis explains each parameter contribution towards deviation of output results due to the variability in input variable data (Abbaspour, 2007). The SWAT-calibration and uncertainty programmes (CUP) is used with SUFI-2 (Sequential Uncertainty Fitting, version. 2) algorithm for sensitivity analysis and calibration. Parameter uncertainty in SUFI-2 includes all sources of uncertainties like climatic variables (e.g. rainfall), model conceptualisation, parameters and measured data (Abbaspour et al, 2004). All uncertainties associated are quantified by a measure as the P-factor, which is the percentage of measured data bracketed by the 95 per cent prediction uncertainty (95PPU). The 95PPU is estimated at 2.5 and 97.5 per cent levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling, by omitting 5 per cent of the worst simulations. d-factor is the average thickness of the 95PPU band divided by the standard deviation of the measured data. Thus SUFI-2 seeks to bracket most of the measured data with the smallest possible uncertainty band (Abbaspour, 2007). The value of P-factor should tend towards one and have a d-factor close to zero. The optimisation process reflects the

sensitivity of the 6 SWAT input variables. Sensitivity analysis is an integral part of model development and involves analytical examination of input parameters to aid in model validation (Yang et al, 2008) and provides guidance for future research (Jha,2011).Surface runoff and base flow variables were treated as the dependent variables and other model parameters were considered as independent variables.Initially, six SWAT

parameters were selected to test surface runoff response sensitivity. These parameters are spatially distributed throughout the watershed and impart some indication of parameter ranges. Curve number changes with changing land use land cover and soil type. Soil hydraulic conductivity varies when land cover changes (Shaw et al, 2014). Parameter sensitivity ranking is shown in Table 7.

Table 7: Sensitivity Ranking of Parameters

S. No.	Parameter	Description	Rank	Relative sensitivity
1	CN2	Initial SCN CN2 value	1	3.46
2	Esco	Soil evaporation compensation factor	2	1.09
3	Alpha_Bf	Base flow alpha factor	3	0.66
4	Sol_Awc	Available water capacity (mm H20/mm soil)	4	0.64
5	Gw_Delay	Groundwater delay (days)	5	0.58
6	Sol_K	Saturated hydraulic conductivity (mm/hr)	6	0.55

Calibration and Validation

Calibration and validation of the model plays an important role in decreasing uncertainty and increasing predictive abilities to make model effective (Khelifa et al,2017).SWAT is a complex model with soil, slope and land use land cover

parameters that can complicate manual model calibration. Four hydrological parameters were identified as most important for model's calibration (Table 8).The results of the sensitivity analysis give the optimal parameters and their auto calibrated values.

Table 8: Optimised Parameters and Calibrated Values

Parameter	Lower bound	Upper bound	Auto calibrated value
ALPHA_BF	0	1	0.524
SOL_AWC	-25	25	1.25
SOL_K	-25	25	1.22
ESCO	0	1	0.01

The comparison of simulated values with the observed runoff during calibration period (Figure 4 and Table 9) gives the correlation coefficient for the monthly simulated runoff which was 0.96, the NSE was 0.88 . p-factor and d-factor 0.48 and 0.64, respectively. Result for

the monthly simulated runoff for calibration period from 2007 to 2009 was found to be reasonable (Moriasi et al,2007) (Figure 5 and Table 9). The simulated and observed runoff for validation period yielded R2=0.82,NSE=0.63,p-factor=0.52 and d-factor=0.62.

Table 9: R²and NSE Values for Calibration (2003-04) and Validation (2007-09)

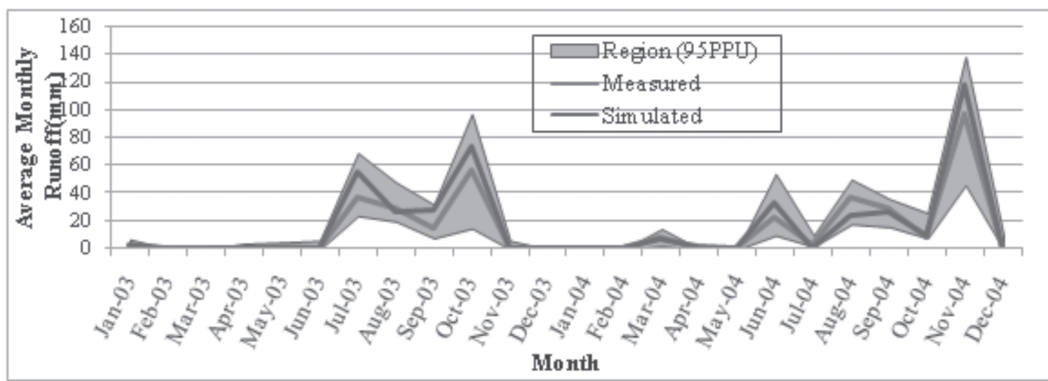| Index	Calibration	Validation
Correlation coefficient	0.96	0.82
Nash-Sutcliffe coefficient	0.88	0.63
P-factor	0.48	0.52
d-factor	0.64	0.62

Figure 4: Comparison Between Simulated and Observed Runoff for Model Calibration from 2003 to 2004. Region (95ppu) Represents the 95 Per Cent Prediction Uncertainty
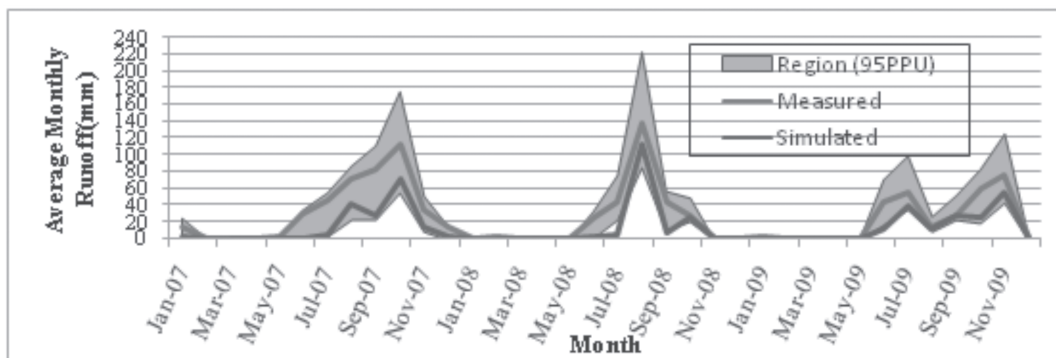

Figure 5: Comparison Between Simulated and Measured Monthly Runoff (Model Validation from 2007 to 2009). Region (95 PPU) Represents 95 Per Cent Prediction Uncertainty

Land Use Land Cover Change Impact on Runoff

A comparison study of different land uses of 2000 and 2010 in Nallamala forest watershed shows significant changes. The results show that during 2000 and 2010, agriculture increased by 9.14 per cent area, and deciduous forest,scrub forest,barren land and water bodies decreased by 2.25, 3.33, 2.03 and 0.8 per cent, respectively (Figure 6).The impact of land use pattern change over 10 years on runoff was analysed with calibrated model parameters for the period from 2003 to 2004 using land use map of 2000 and 2007 to 2009 using land use map 2010 while using same DEM and soil maps.
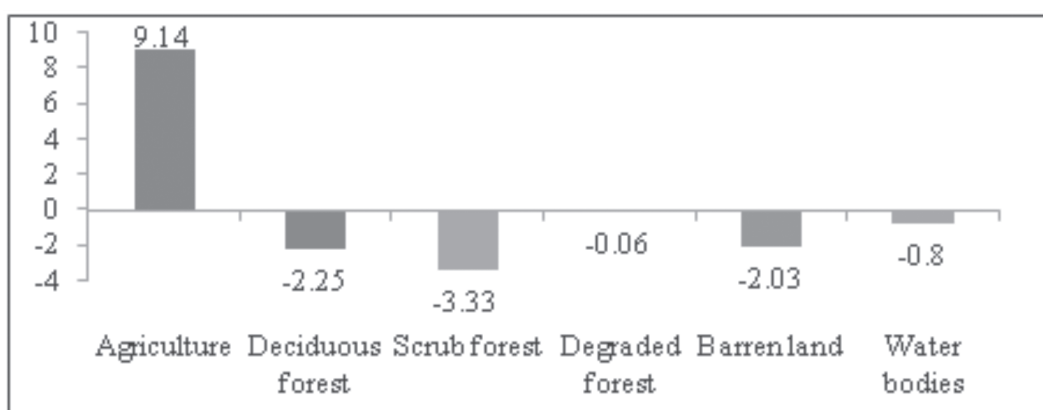

Figure 6: The Percentages of Area Change of Each Land Use for 2000 to 2010

The resulting predictions of annual runoff (Figure 7) indicate that, compared to the land use in 2000, the annual runoff is higher in each land use type (Ohana-Lev et al,2015). The increased annual runoff is due to change in agriculture land and forest area which decreases water infiltration and increased rate of evapotranspiration.

To investigate the influence of land use type on runoff, we used different land use types of 2000 and 2010 to compare annual mean runoff. The runoff is more sensitive to forest land to agriculture and barren land type. The major cause for increase in annual mean runoff is shift in land use type which further alters infiltration and percolation.

Total 44 sub-basins under the same climatic conditions, but different land use types resulted in noticeable change in spatial distribution of runoff (Figure 8). The 2010 land use type had resulted in greatest influence on runoff. Larger area of deciduous and scrub forest had been converted into agriculture and barren land. The estimates of annual mean runoff calculated across 44 sub-basins were classified into seven runoff categories (Figure 8).
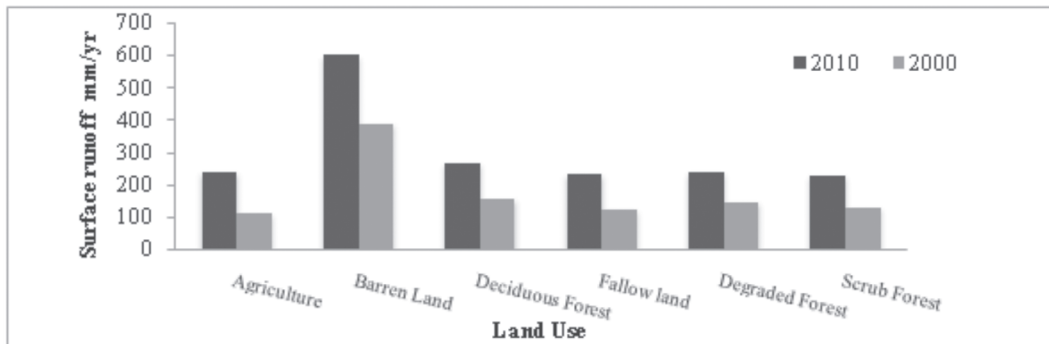
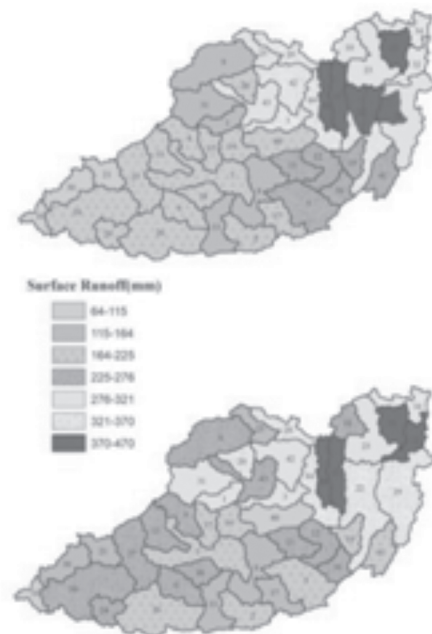**Figure 7: Comparison of Surface Runoff from Six Land Use Types for Simulation Period of 2000 to 2010**

Figure 8: The Spatial Distribution of Annual Mean Runoff for 2000 and 2010 in 44 Sub-basins for Different Land Use Conditions

Comparing the number of sub-basins that shifted to another runoff category explain that over a period 2000 to 2010, the area classified as 276-321 mm runoff category, increased by 2 per cent, 370-470mm by 8 per cent . The area under 225-276mm category declined by 18 per cent. According to the land use changes from 2000 to 2010 made the sub-basins more vulnerable to soil erosion because of slope and land use change.

Conclusion

The study investigated the impacts of land use change on runoff using hydrological modeling. Using SWAT model, hydrological parameters of the Nallamala watershed, India simulated using different land use types over a decade. Statistical evaluation between simulated and observed runoff values are found to be best fit. The sensitivity of four SWAT parameters is found to be most sensitive parameter for hydrological response (Arnold et al,1999;Spruill et al,2000). The results show that land use type is an important factor to determine the hydrological response in the study area. Major changes in the deciduous forest and scrub forest area were the major factors in the amount of runoff produced. Future conversion of forest to agriculture and barren land may lead to other ecological and hydrological problems like soil erosion and river sedimentation. Catchment area or watershed basins are often characterised with complex spatial and temporal nature with different land use types. To improve watershed management and decision making, new technological models such as SWAT are useful tools for investigation of hydrological responses. High degree of uncertainty associated with land use and hydrological models is often a major limitation. This uncertainty is due to lack of data and quality of data. A hydrologic model gives the needed quantitative information important to the decision-making process concerning land and water resources planning and management.

References

Abbaspour K.C, Johnson C.A. and Van Genuchten M.T(2004),"Estimating uncertain flow and transport parameters using a sequential uncertainty fitting procedure," *Vadose Zone Journal*, 3(4):1340-1352.

Abbaspour K C. (2007), "User Manual for SWAT-CUP, SWAT Calibration and Uncertainty Analysis Programs. Swiss Federal Institute of Aquatic Science and Technology," Eawag: D¨ubendorf, Switzerland.

Arnold J.G, Srinivasan R, Muttiah R.S. and Williams J.R (1998),"Large area hydrologic modeling and assessment part I: model development," *Journal of the American Water Resources Association,* 34 (1):73-89.

Arnold J.G, Srinivasan R, Muttiah R.S. and Allen P.M (1999),"Continental scale simulation of the hydrologic balance,"*Journal of the American Water Resources Association*, 35 (5):1037-1051.

Brath A, Montanari A. and Moretti G (2006), "Assessing the effect on flood frequency of land use change via hydrological simulation (with uncertainty),"*Journal of Hydrology*, 324 (1):141–153.

Breuer L, Huisman J.A, Willems P, Bormann H, Bronstert A, Croke B.F.W, Frede H.G, Gräff T, Hubrechts L, Jakeman A.J and Kite G (2009),"Assessing the impact of land use change on hydrology by ensemble modeling (LUCHEM). I: Model intercomparison with current land use,"*Advances in Water Resources*, 32(2): 129-146.

Costa M. H, Botta A. and Cardille J.A (2003),"Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia," *Journal of Hydrology*, 283:206–217.

Gassman, P.W, Reyes M.R, Green C.H. and Arnold J.G (2007),"The soil and water assessment tool: historical development, applications, and future research directions," *Transactions of the ASABE*, 50 (4):1211-1250.

Giri C, Pengra J. and Loveland T.R (2013),"Next generation of global land cover characterization, mapping, and monitoring,"*International Journal of Applied Earth Observation and Geoinformation*, 25: 30–37.

Githui F, Mutua F and Bauwens W (2009),"Estimating the impacts of land-cover change on runoff using the soil and water assessment tool (SWAT): case study of Nzoia catchment, Kenya," *Hydrological Sciences Journal*, 54 (5): 899-908.

Hernandez M, Miller S.N, Goodrich D.C, Goff B.F, Kepner W.G, Edmonds C.M. and Jones K.B (2000),"Modeling runoff response to land cover and rainfall spatial variability in semi-arid watersheds," *Environmental monitoring and assessment*, 64 (1): 285-298.

Jha M.K (2011),"Evaluating hydrologic response of an agricultural watershed for watershed analysis", *Water*, 3 (2): 604-617.

Khelifa W.B, Hermassi T, Strohmeier S, Zucca C, Ziadat F, Boufaroua M.and Habaieb H (2017),"Parameterization of the effect of bench terraces on runoff and sediment yield by Swat modeling in a small semi arid watershed in Northern Tunisia," *Land Degradation & Development*,28: 1568–1578.

Li Z, Liu W.Z, Zhang X.C and Zheng F.L (2009),"Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China,"*Journal of hydrology*, 377(1): 35-42.

Moriasi D.N, Arnold J.G, Van Liew M.W, Bingner R.L, Harmel R.D and Veith T.L (2007),"Model evaluation guidelines for systematic quantification of accuracy in watershed simulations," *Transactions of the ASABE*, 50 (3):885-900.

Neitsch S.L, Arnold J.G, Kiniry J.R. and Williams J.R (2005), Soil Water Assessment Tool, Theoretical Documentation, Temple Texas.

Ohana-Levi N, Karnieli A, Egozi R, Givati A. and Peeters A (2015),"Modeling the effects of land-cover change on rainfall-runoff relationships in a semiarid, eastern mediterranean watershed," *Advances in Meteorology*, 2015:1-16.

Shaw B.S, John M, Nishan B. and Lindi Q(2014),"Longitudinal study of the impacts of land cover change on hydrologic response in four mesoscale watersheds in New York State, USA,"*Journal of Hydrology*, 519:12–22.

Spruill C.A, Workman S.R. and Taraba J.L (2000),"Simulation of daily and monthly stream discharge from small watersheds using the SWAT model, Transactions of the ASAE, 43 (6), 1431.

Wang G.X, Zhang Y, Liu G.M. and Chen L (2006),"Impact of land-use change on hydrological processes in the Maying River basin, China,"*Earth Sciences*, 49 (10): 1098–1110.

Yang J, Reichert P, Abbaspour K.C, Xia J. and Yang H (2008),"Comparing uncertainty analysis techniques for a SWAT application to the Chaohe Basin in China," *Journal of Hydrology*, 358 (1-2):1-23.