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Impact assessment of land use land cover change on sediment yield using SWAT Model

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ABSTRACT

Quantifying the impacts of land use change and land cover practices on the hydrological response of a watershed has been an area of interest for the hydrologists in recent years as this information could serve as a basis for developing sound watershed management interventions. This thesis aims at evaluating the effects of land use land cover change on sediment yield using SWAT model simulation in Gadarwara watershed located in Narmada Basin. The degree and type of land cover influences the rate of infiltration, runoff and total sediment loads transported from a watershed. It often results in significant degradation of land resources such as loss of soil by erosion, nutrient leaching and organic matter depletion. However very few studies in India, have used the physically based hydrological models along with the land use land cover change conditions. Hence in this current work SWAT model has been used to assess the impact of land use land cover changes on monthly sediment of Narmada River Basin. The SWAT model has been calibrated and validated against the monthly streamflow for the gauging station of Gadarwara, situated along the Shakkar River. The results depict that SWAT model usually performs well in simulating runoff according to Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R2) and Percentage bias (PBIAS) values. For stream flow the NSE, R2 and PBIAS values were 0.86, 0.89, 12.2 during calibration period and 0.83, 0.87 and 14.5 during validation period respectively. For sediment the efficiency decreased due to less availability of data and the NSE, R2 and PBIAS values were 0.66, 0.68 and -10.9 during calibration period and 0.65, 0.67 and -5 during validation period respectively. The results of the study indicated that increase in forested areas result in decreasing sediment yield Agriculture land contributes mainly in sediment yield hence reduction in agriculture land leads in reduction of sediment yield and increase in agriculture land results in increase of sediment yield.

Keywords— *Land Use Land Cover Change, Civil Engineering, Sediment Yield, Swat Model*

1. INTRODUCTION

Land and water are the two most vital natural resources of the world and these resources must be conserved and maintained carefully for environmental protection and ecological balance. Prime soil resources of the world are finite, non-renewable over the human time frame, and prone to degradation through misuse and mismanagement. In India, out of a total geographical area of 328 M ha, an estimated 175 M ha of land, constituting an area of 53% suffers from deleterious effect of soil erosion and other forms of land degradation and with the increasing population pressure, exploitation of natural resources, faulty land and water management practices, the problem of land degradation will further aggravate. Land use change within a region has not only an impact on various hydrologic landscape functions but also affects the habitat quality and thus the biodiversity of a landscape.

Land use change, including land conversion from one to another and land cover modification through land use management has greatly altered a large proportion of the earth's land surface to satisfy mankind's immediate demands for natural resources (Rahman et al 2012). Land use change can be characterized by the complex interaction of behavioral and structural factors associated with demand, technological capacity, and social relations, which affect both demand and environmental capacity, as well as the nature of the environment in question (Verburg et al., 2004). The impacts of land use changes have received considerable attention from ecologists, particularly with respect to effects on aquatic ecosystems and biodiversity (Turner et al., 1996 cited in Verburg et al., 2004).

Land use changes in a watershed can impact water supply by altering hydrological processes such as infiltration, groundwater recharge, base flow and runoff (Turner et al., 1996 cited in Verburg et al., 2004). Estimates of runoff volumes and sediment yields from watersheds help to predict the volume of silt that will collect in the water body.

Land use is rated as one of the most important factors influencing water quantity and quality in watersheds. Not only are hydrological processes such as evapotranspiration, infiltration, surface runoff and groundwater flow altered substantially by land use changes, but also soil erosion and the transport of sediment to water bodies (Bultot et al. 1990; Fohrer et al. 2001; Lin et al. 2007; Sahin and Hall 1996; Tong and Chen 2002).

Land use changes in catchments are always due to man-made causes, mainly attributed to the search for resources to meet human needs. As a result, the ecosystem within the catchment gets adversely affected leading to a decline in land productivity, water scarcity, and catchment degradation through deforestation, hence the need to promote sustainable utilization of land and water resources within a catchment. In this regard therefore, an integrated approach in water resource planning, conservation and management is necessary.

2. MATERIALS AND METHODS

2.1 Study Area

The present study is done for Sakkar river which is a tributary of Narmada River Basin of Madhya Pradesh in India. A catchment area of Narmada River basin has been considered as our study area which covers the gauging station of Gadarwara, situated in the Narsinghpur district of Madhya Pradesh. The geographical extent of this catchment is 2206 square kilometers spreading from longitude 78º 46’ 39” to 79º 16’ 59”E and from latitude 22º 21’ 25” to 22º 55’ 49”N.

The Shakkar river rises in the Satpura range, east of the Chhindi village, Chhindwara district, Madhya Pradesh an elevation of about 600 m at latitude 22°23′ N longitude 78°52′ E (Figure 1). The watershed covers 2206 km2 area.

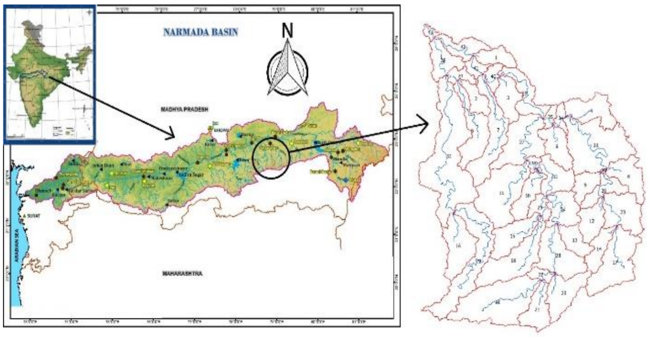

Fig. 1: Location of study area

2.1.1 Topography: The study area lies in Narsinghpur district in the state of Madhya Pradesh, India. 73.51% area of watershed falls under 455-857m elevation and 90.59% area of watershed falls under 338-857m elevation. The minimum and maximum elevation of watershed is 324m and 1180m respectively.

2.1.2 Climate: The climate of the basin is generally dry except the southwest monsoon season. The southwest monsoon starts from middle of June and lasts till end of September. October and middle of November constitute the post monsoon or retreating monsoon season. The normal annual rainfall is 1192.1mm. The normal maximum temperature received during the month of May is 42.50 C and minimum during the month of January is 8.20 C (Gajbhiye et al., 2013b).

2.1.3 Land Use/Land Cover: Forested area covers the major part of the basin (61%) which is mainly dominated by deciduous forests followed by Agriculture Land (32%). The presence of alluvial soil in the basin attributes to extensive agriculture in the lower reaches of basin. The land use/ land cover in the region has not undergone very significant changes over the last decade with agriculture and forests covering the major part of the region.

2.1.4 Soils: Soils are mainly clayey to loamy in texture with calcareous concretions invariably present. They are sticky and in summer, due to shrinkage, develop deep cracks. They generally predominate in montmorillonite and beidellite type of clays. In rest of alluvial areas, mixed clays, black to brown to reddish brown, derived from sandstones and traps is observed which is sandy clay in nature with calcareous concretions. Near the banks of the rivers and at the confluence, light yellow to yellowish brown soils are noticed which were deposited during the recent past. These soils are clayey to silt in nature (Mishra et al., 2013; Gajbhiye et al., 2014b,c).

Gadarwara watershed has basaltic terrain upward and a broad alluvial terrain in its middle and lower reaches. The alluvial plain through which Shakker river runs after cutting across the Satpura range emerges in openness at Hathanapur villlage. From Hathanapur down to confluence, it is generally, an alluvial plain. Alluvial soil face recession which is one of the prominent processes of badland formation and in this process; on gaining moisture the slope collapses because of no stress perpendicular to the face resisting pore water pressure. Around 70.27% of the basins consists of clayey soils. 29.73% of the basin comprises of black soil.

2.2 Model Setup

2.2.1 Theory of SWAT: Hydrology simulation of a watershed in SWAT is separated into two major phases. Land phase controls the amount of water, sediment, nutrient and pesticide loading to the main channel in each sub basin. Water or routing phase controls the movement of water, nutrients and sediments through the channel network of the watershed to the outlet. Each sub basin in SWAT is discretized into a series of Hydrologic Response Units (HRUs), which are unique in soil-land use-slope combinations.

Hydrologic simulation of SWAT is based on the water balance equation:

$$SW_t = SW_0 +_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{Seep} - Q_{gw})$$

Where,

SW_t	is final soil water content [mm],
SW_0	is initial soil water content [mm],
t	is time [days],
R_{day}	is amount of precipitation on a day i [mm],
Q_{surf}	is amount of surface runoff on a day i [mm],
E_a	is amount of evapotranspiration on a day i [mm],
W_{seep}	is amount of percolation and bypass flow exiting the soil profile bottom on a day i [mm],
Q_{gw}	is amount of return flow on a day i [mm].

SWAT provides two methods for surface runoff estimation. The first one is based on the Soil Conservation Service curve number procedure and the second one estimates runoff height using the Green and Ampt infiltration method.

Soil erosion caused by rainfall and runoff is computed by the Modified Universal Soil Loss Equation (MUSLE).

$$\mathrm{Sed} = 11.8 \times \left(\mathrm{Q_{surf}} \times \mathrm{q_{peak}} \times \mathrm{area_{hru}}\right)^{0.56} \times \mathrm{K_{USLE}} \times \mathrm{C_{USLE}} \times \mathrm{P_{USLE}} \times \mathrm{LS_{USLE}} \times \mathrm{CFRG}$$

Where,

Sed	is the sediment yield on a given day (metric tons),
Q_{surf}	is the surface runoff volume (mm H2O ha-1),
q_{peak}	is the peak runoff rate (m3 s-1),
$area_{hru}$	is the area of the HRU (ha),
K_{USLE}	is the USLE soil erodibility factor,
C_{USLE}	is the USLE cover and management factor,
P_{USLE}	is the USLE support practice factor,
LS_{USLE}	is the USLE topographic factor, and
CFRG	is the coarse fragment factor.

In the routing phase, SWAT uses Manning's equation to calculate the rate and velocity of flow. Water is routed through the channel network using the variable storage routing method or the Muskingum river routing method. The maximum amount of sediment that can be transported from each segment of the stream is calculated by the simplified Bagnold's equation.

2.2.2 Model Setup and Inputs: The model set-up was done with the help of QSWAT interface package that runs under QGIS environment. The set up consisted of preparation of the input data, delineation of watershed using the digital elevation model (DEM) data, HRU definition using soil, slope, land use and agricultural practice data, weather data definition and finally a test run of the model. It is followed by calibration and validation of the data considered.

2.2.3 Digital Elevation Model (DEM) of the Study Area: Digital Elevation Model is the geographic grid of an area where the contents of each grid cell give a description of the elevation of any point at a given location and specific spatial resolution in form of a digital file. It is one of the essential spatial input for delineation of watershed in to a number of sub basins on the basis of elevation in SWAT model. In this work, a DEM map of 1:50,000 scale and a 30m x 30m resolution has been obtained from SRTM digital elevation data produced by NASA originally in form of tiles from the world data base. These tiles have been mosaiced to obtain a single map. A shape file was created for the river basin considered by us with the help of QGIS software which was then clipped in the merged DEM map to obtain the required DEM of the Shakkar river basin. The DEM downloaded from the USGS website is then projected in the WGS 84 / UTM zone 44N zone.

Fig. 2: DEM Map

2.2.4 Land Use/ Land Cover: The land use maps for Madhya Pradesh were obtained from NRSC (ISRO) which was clipped with the shape file to obtain the required land use map of the Gadarwara watershed. Originally NRSC (ISRO) classifies the land use into

18 classes which was reduced to 6 categories with the help of reclassification using GIS tools to reduce the number the HRUs and easy interpretation.

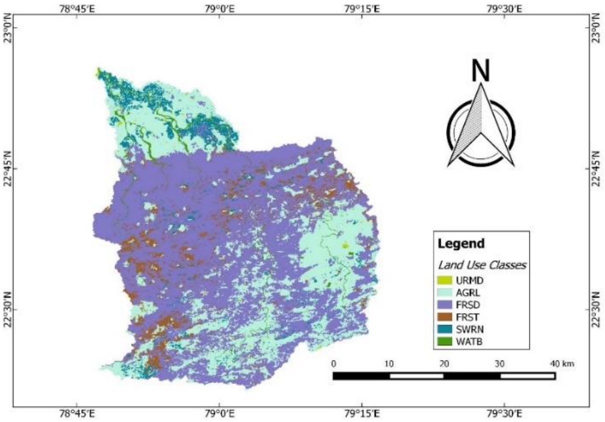

Fig. 3: Land Use/Land Cover

S. No.	SWAT Code	Land Use Category	Corresponding SWAT Definition	Area [ha]	%Watershed
1	URMD	Urban	Urban Medium Density	545.26	0.25
2	AGRL	Agriculture	Agricultural Land-Generic	69372.66	31.46
3	FRSD	Forest	Forest-deciduous	120526.78	54.65
4	FRST	Forest	Forest-mixed	15565.87	7.06
5	SWRN	Wasteland	Wasteland-South western (Arid)Range	11628.94	5.27
6	WATB	Water	Water	2904.57	1.32

2.2.5 Soil: The FAO–UNESCO global available soil data (1:500,000 scale) in vector format was downloaded from the FAO GeoNetworkportal. Then the soil data acquired from FAO website was used to generate soil input data for the model. The global soil map was clipped with the shape file of the river basin to obtain the soil map of the required area.

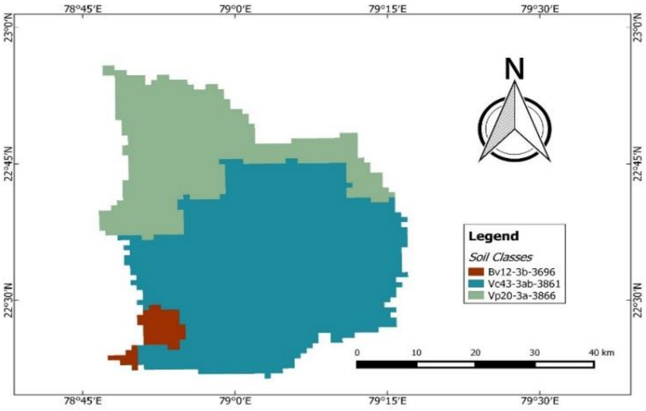

Fig. 4: Soil

Table 1: Soil classes

S. No.	FAO Soil Class	Soil Texture	Area [ha]	%Watershed
1	Bv12-3b-3696	Clay Loam	6504.16	2.95
2	Vp20-3a-3866	Black soil	65570.61	29.73
3	Vc43-3ab-3861	Clay	148469.31	67.32

2.2.6 Metrological Data: Meteorological data is one of the most important datasets for analysis of watershed. Daily climate inputs for the time span of 1991-2005 including precipitation and minimum and maximum temperature were obtained from the Indian Meteorological Department. The parameters like wind speed, solar radiation and humidity were obtained from swat.tamu.edu and related parameters were generated for weather generator for QSWAT model.

2.3 Model Simulation

The daily discharge data for the considered catchment was obtained for the time period January 1996 to Dec 2005. This set of data was used for comparison with set of simulated data generated by the SWAT model and for further calibration and validation.

- 10 years of data have been considered in this particular study.
- Nine model runs have been performed here, one for the calibration for which the calibration is done with the help of SWAT CUP, second for validation of model after calibrating and rest of the runs are for six scenarios for different land use changes.
- Number of years to skip (NYSKIP) i.e. Warmup period = 5 years (1991-1995).
- Calibration period = 5 years (1996-2000)
- Validation period = 5 years (2001-2005).

- The model simulation has been done using QSWAT model following which the calibration and validation of the model has been done using SWAT CUP tool using SUFI-2 (Sequential Uncertainty Fitting version 2) algorithm.

2.4 Scenarios

To explore the sensitivity of sediment yield to the effect of land use/land cover changes on the Gadarwara watershed under different land use/land cover scenarios. The percent coverages and details of the conversions are presented in the tables at the end of this section. The land use scenarios included; In total 12 scenarios were generated for different land use change conditions that are given below in the table 2.

Table 2: Description of scenarios

S.N.	Scenarios	Abbreviation	Discription
1	Land Use Change Scenario 1	LUC1	10% of Agriculture land converted to Urban land
2	Land Use Change Scenario 2	LUC2	20% of Agriculture land converted to Urban land
3	Land Use Change Scenario 3	LUC3	50% of Agriculture land converted to Urban land
4	Land Use Change Scenario 4	LUC4	10% of Agriculture land converted to Forested land
5	Land Use Change Scenario 5	LUC5	20% of Agriculture land converted to Forested land
6	Land Use Change Scenario 6	LUC6	50% of Agriculture land converted to Forested land
7	Land Use Change Scenario 7	LUC7	10% of Forested land converted to Urban Land
8	Land Use Change Scenario 8	LUC8	20% of Forested land converted to Urban Land
9	Land Use Change Scenario 9	LUC9	50% of Forested land converted to Urban Land
10	Land Use Change Scenario 10	LUC10	10% of Forested land converted to Agriculture land
11	Land Use Change Scenario 11	LUC11	20% of Forested land converted to Agriculture land
12	Land Use Change Scenario 12	LUC12	50% of Forested land converted to Agriculture land

Along with all 12 land use land cover change scenarios base line scenario was also generated according to which all the 12 land use land cover change scenarios were evaluated.

2.5 Calibration and Validation

Simulation and calibration of the model was carried out for the time period of 1991 to 2000 which included the warmup period of five years i.e. from 1991 to 1995. The calibrated model was further validated for the period of 2001 to 2005 which is about one-third of the total study period. Model was calibrated for stream flow and sediment yield. In the process of calibration of stream flow the most sensitive model parameters were found to be the runoff curve number (CN2), the soil evaporation compensation factor (ESCO), and the available soil water capacity (SOL_AWC) that governs surface flow. The baseflow alpha factor (ALPHA_BF), deep aquifer percolation fraction (RCHRG_DP) and threshold depth of water in the shallow aquifer (GWQMN), Groundwater delay in days (GW_DELAY), Groundwater revap coefficient (GW_REVAP), Threshold depth of water for revap to occur (REVAPMN) were among parameters that governed the flow. Other six parameters that are found to be sensitive for sediment yield are USLE equation support practice factor(USLE_P.mgt), Linear parameter in sediment transport equation(SPCON.bsn), Exponent parameter for calculating sediment re-entrained in channel sediment routing(SPEXP.bsn), Channel erodibility factor(CH_COV1.rte), Channel cover factor(CH_COV2.rte), USLE equation soil erodibility (K) factor(USLE_K.sol).

During calibration period for stream flow the NSE, R2 and PBIAS values were 0.86, 0.89, 12.2 and 0.83, 0.87 and 14.5 during validation period respectively. For sediment the NSE, R2 and PBIAS values were 0.66, 0.68 and -10.9 during calibration period and 0.65, 0.67 and -5 during validation period respectively.

3. RESULTS AND DISCUSSIONS

3.1 Impact of Land Use Changes on Sediment Yield

3.1.1 Condition 1: Conversion of Agriculture land to Urban land

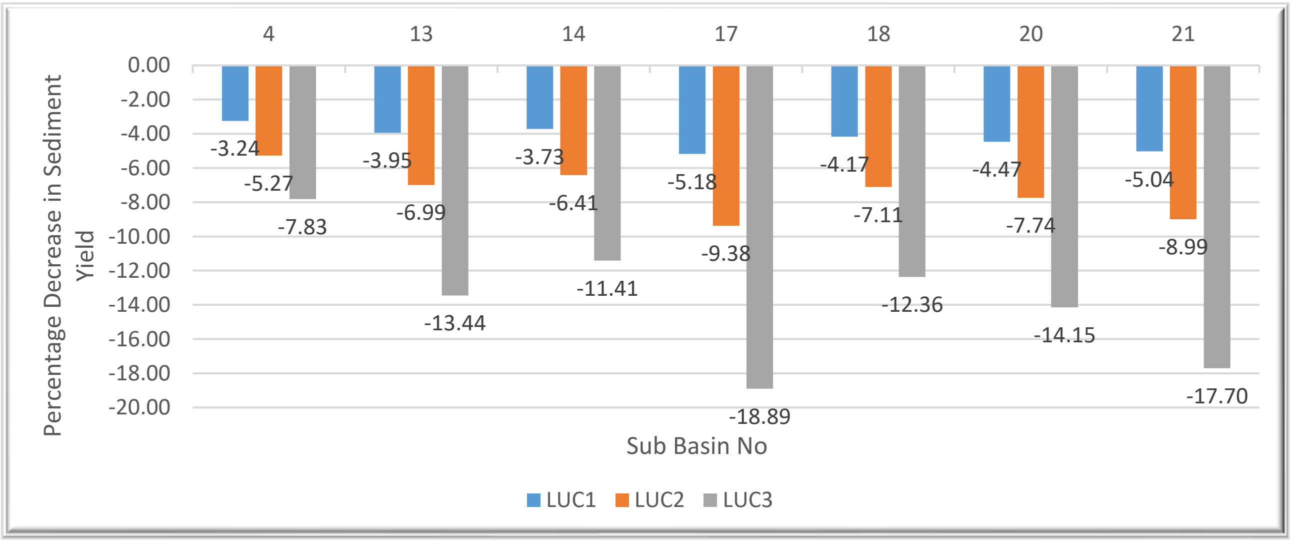

Fig. 5: Scenarios LUC 1, 2, 3

3.1.2 Condition 2: Conversion of Agriculture land to Forested land

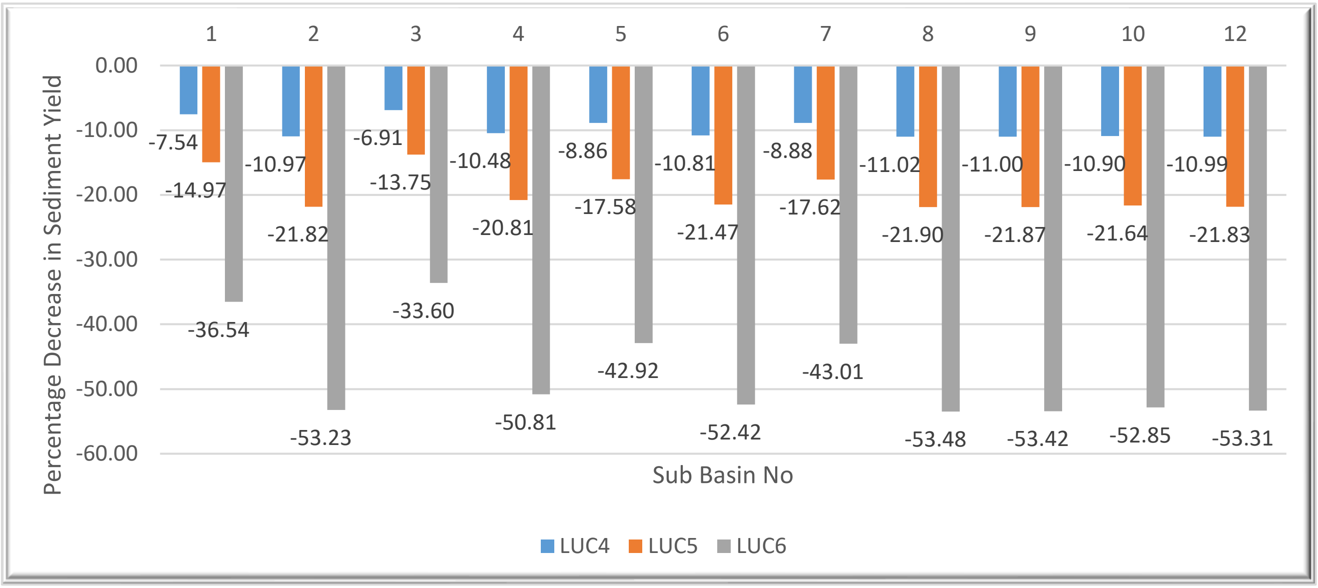

Fig. 6: Scenarios LUC 4, 5, 6

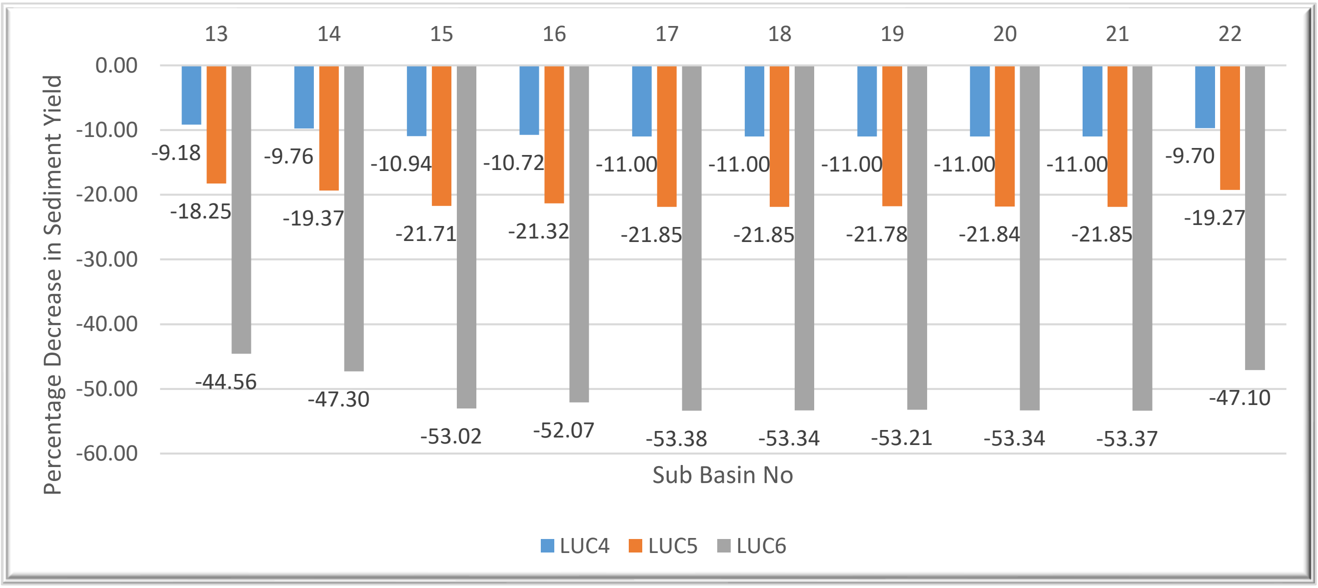

Fig. 7: Scenarios LUC 4, 5, 6

3.1.3 Condition 3: Conversion of Forested land to Urban land

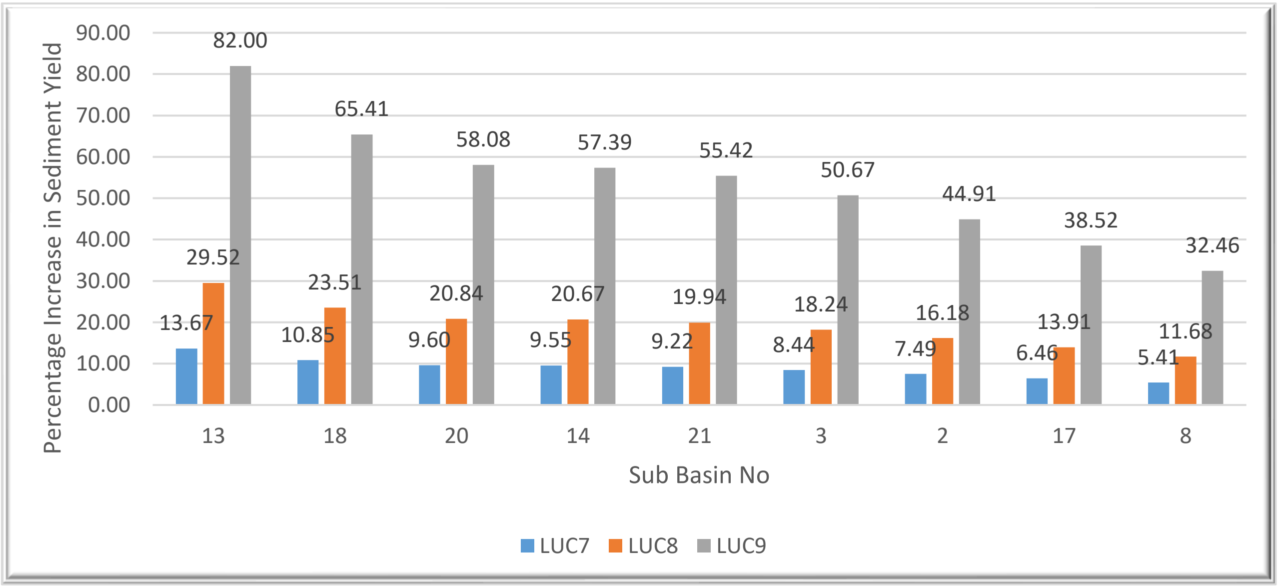

Fig. 8: Scenarios LUC 7, 8, 9

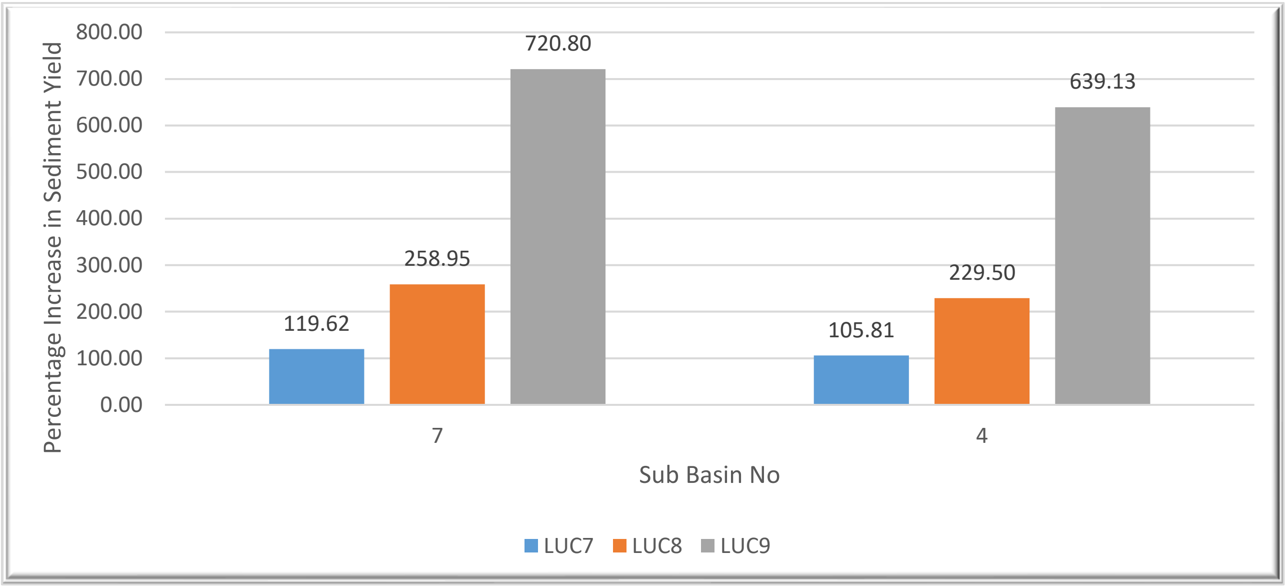

Fig. 9: Scenarios LUC 7, 8, 9

3.1.4 Condition 4: Conversion of Forested land to Agriculture land

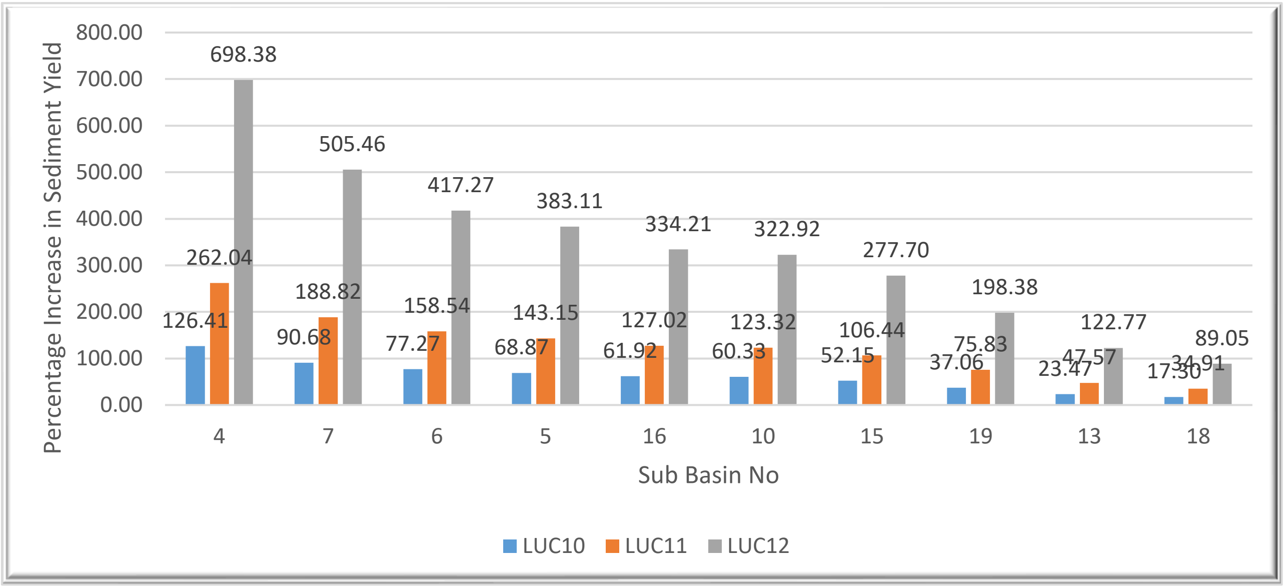

Fig. 10: Scenarios LUC 10, 11, 12

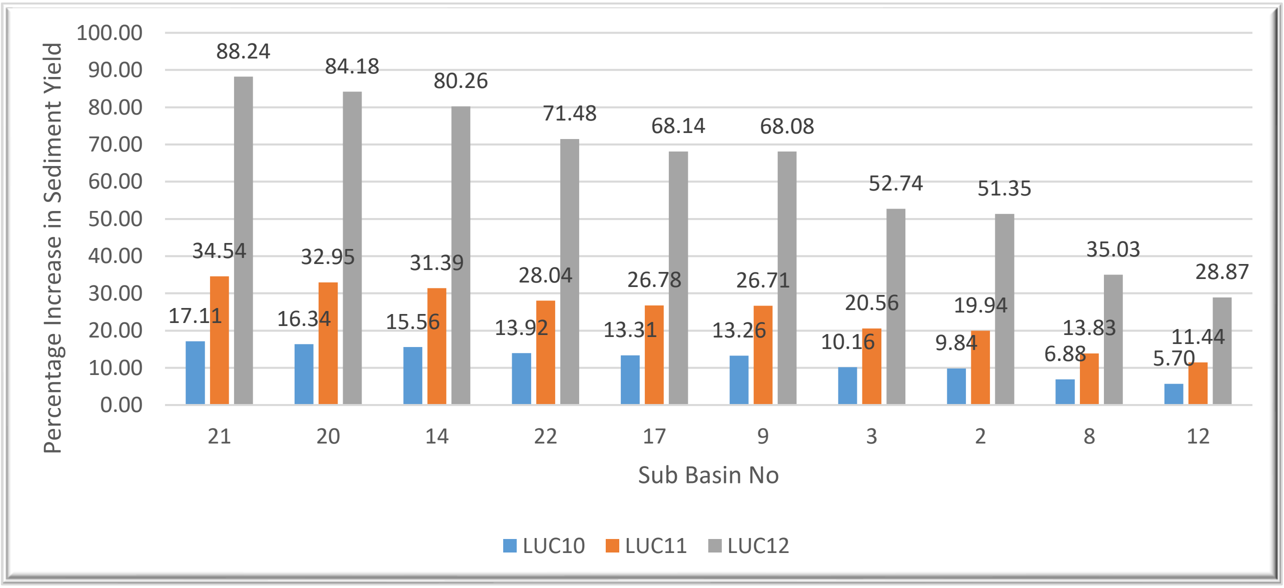

Fig. 11: Scenarios LUC 10, 11, 12

The results of this study indicate a strong need for sustainable development and management of land use in the watershed. They show that cultivated sloping lands are the main contributors to soil loss and sediment yields. In spite of the uncertainties associated with the model output, the results of the land use scenario simulations are helpful for developing a sustainable watershed management plan. They give an idea about the general reaction of hydrological and sediment related processes to possible future land use changes. As all scenarios for a watershed are subject to the same input data uncertainty, it can be assumed that differences in scenario results can in fact be attributed to the applied scenario changes.

Simulation results demonstrate that soil loss and sediment loads have decreased with the increase in forested area. However, an increasing indicates that under the modified conditions in the inputs are still critical.

Simulation results have demonstrated that a further afforestation of cropland would effectively reduce sediment inputs. However, this is not considered to be feasible as long as the livelihood of a large number of people in the Catchment depends on agriculture. Scenario simulations have also indicated that the conversion of forest to agriculture land would critically increase sediment yields from the catchment. The amount of sediment inputs does not necessarily equal the soil loss from agriculture land, because parts of the eroded material can be deposited and stored during transport to the river.

The results of the scenario simulations are helpful for developing a sustainable watershed management plan. They give an idea about the order of magnitude of the reaction of the water and sediment related processes to possible future land use changes. However, they do not include alterations of crop rotations or tillage practices or the implementation of soil conservation practices. Therefore, they do not support the actual formulation of watershed management plans yet.

No matter how much information and data are available for a watershed, there will always be a certain amount of error and uncertainty in model results. After all, models are mathematical representations of an extremely heterogenous reality that is subject to unpredictable natural variability. However, estimating the impacts of human interferences with nature is crucial to sustain adequate living conditions for all inhabitants of this planet. A basic database for future research was created and the most important sources of uncertainty were identified.

4. CONCLUSIONS

The current study can be concluded in the following manner:

The area considered for the present work is a catchment area of Shakkar river basin. The study has been conducted for Shakkar River, a tributary of Narmada River. QSWAT tool which runs under QGIS interface has been chosen to model the runoff discharge for the basin. Simulated discharges have been calibrated with the observed discharges for the time period of 1996 to 2000 and validated for the time period 2001 to 2005.

- 43 sub-basins and 392 HRUs are found to exist for the region from the delineation result.
- Sub-basin no 4,13,14,17,18,20,21 are more sensitive for LUC 1, 2, 3 under which agriculture land converted to urban land 10%, 20% and 50% respectively.
- Under these scenarios' sediment yield is found to be reduced by a maximum value of 5.18%, 9.38%, and 18.89% respectively for scenarios LUC1, 2, 3 in sub-basin no 17.
- Sub-basin no 1,2,3,4,5,6,7,8,9,10,12,13,14,15,16,17,18,19,20,21,22 are more sensitive for LUC4,5,6 under which agriculture land converted to forested land 10%, 20% and 50% respectively.
- Under these scenarios' sediment yield is found to be reduced by a maximum value of 11.02%, 21.90%, and 53.48% respectively for scenarios LUC 4, 5, 6 in sub-basin no 8.
- Sub-basin no 2,3,4,7,8,13,14,17,18,20,21 are more sensitive for LUC7,8,9 under which forested land converted to urban land 10%, 20% and 50% respectively.
- Under these scenarios' sediment yield is found to be increased by a maximum value of 119.62%, 258.95%, and 720.80% respectively for scenarios LUC 7, 8, 9 in sub-basin no 7.
- Sub-basin no 4,13,14,17,18,20,21 are more sensitive for LUC 10, 11, 12 under which forested land converted to agriculture land 10%, 20% and 50% respectively.

Under these scenarios' sediment yield is found to be increased by a maximum value of 126.41%, 262.04%, and 698.38% respectively for scenarios LUC 10, 11, 12 in sub-basin no 4.

5. CONCLUSIONS

This paper emphasizes that SWAT is a very flexible for Land-hydrologic models have proven to be efficient tools to meet the increasing demand for quantitative information on water availability and quality especially in response to changes in land-use, land management or climate. SWAT model is a potential and powerful model once calibrated and validated effectively for wide range of applications. The development of GIS-based interfaces, which provide a simple means of translating digital land use, topographic, and soil data into model inputs, has greatly facilitated the process of configuring SWAT for a given catchment. Furthermore, advancement of a new era in SWAT application for LUCC simulation with the highest possible accuracy as a result of the new facilities for SWAT auto-calibration and uncertainty analysis was presented. Simulation of hypothetical, real and future scenarios.
A key strength of SWAT is its flexible framework that allows the simulation of a wide variety of conservation practices and other BMPs, such as fertilizer application, cover crops (perennial grasses), filter strips, conservation tillage, irrigation management, flood-prevention structures, grassed waterways, and wetlands. Simulation of hypothetical, real and future scenarios in SWAT has proven to be an effective method of evaluating alternative land use effects on runoff, sediment and pollutant losses. This capability has been strengthened via the integration of SWAT with LULC simulation models.

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