Impact Assessment of Land Use Land Cover Change on Sediment Yield Using Swat Model: A Review

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Abstract— Land and water are the two most important resources of the world and these resources must be preserved and maintained carefully for environmental protection and ecological balance. Prime soil resources of the world are finite, non-renewable and susceptible 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, misuse of natural resources, faulty land and water management practices, the problem of land degradation will further aggravate. Land use change within an area has not only an impact on numerous hydrologic landscape functions but also affects the habitat quality and thus the biodiversity of a landscape.

Keywords: Sediment Yield, Swat Model

I. Introduction

Land cover data gives an estimate of how much of an area is covered by forests, vegetation, impermeable surfaces, wetlands and other land and water types. Water types consists of open water or wetlands. Land use gives an idea about how the landscape is being used by people – whether for development, conservation, or for mixed uses. Measuring the impacts of land use change and land cover change on the hydrological response of a watershed has been an interesting area for the hydrologists in recent years as this information could serve as a basis for developing sound watershed management (Ayana et al.,2014).

The effects of land use and land cover changes on the hydrological response of a watershed are most likely where the surface characteristics of a watershed experiences alternation due to changes. The degree and type of land cover influences the rate of infiltration, runoff, and subsequently the volumes of surface runoff and total sediment loads transported from a watershed. It often results insignificant degradation of land resources such as loss of soil by erosion, nutrient leaching and organic matter reduction. For example, land use change can result in change of flood frequency & severity, variation in base flow, and change in annual mean discharge. Moreover, land use change has a direct effect on watershed management practices, economic health and social processes of concern at regional, national and global levels.

Sediments are a very important component in hydropower development in many countries. High sediment rates leads to filling of reservoirs and loss of live storage, which ultimately leads to loss of production potential of reservoir. Moreover, evacuation of sediments from reservoirs is a costly process that can have large ecological impacts. Simulation of sediment yield can be a tool to estimate sediment load to reservoirs, and to evaluate how much sediment is generated from various land types. This can be important in evaluating the sustainability of reservoirs and to evaluate mitigation measures in catchments and in the evaluation of effects of compensatory land use in the case of new development. Such tools can also be important in studies of land use changes and to assessing the effect of rainfall intensity on sediment yield in studies of current and future sediment concerns which are important in studies of global change. This paper aims to assess the effect of land use land cover change on sediment using SWAT model.

II. 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:

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

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).

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

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.

III. IMPACT OF LAND USE LAND COVER CHANGE BY USING SWAT:

Land cover data gives an estimate of how much of an area is covered by forests, vegetation, impervious surfaces, wetlands and other land and water types. Water types consists of open water or wetlands. Land use gives an idea about how the landscape is being used by people – whether for development, conservation, or for mixed uses. 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 involvements (Ayana et al., 2014). The effects of land use and land cover changes on the hydrological response of a watershed are most likely where the surface characteristics of a watershed undergoes alternation due to changes. The degree and type of land cover influences the rate of infiltration, runoff, and therefore the volumes of surface runoff and total sediment loads transported from a watershed. It every so often results insignificant degradation of land resources such as loss of soil by erosion, nutrient leaching and organic matter depletion. For example, land use change can result in change of flood frequency, flood severity, fluctuation in base flow, and change in annual mean discharge. Furthermore, land use change has a direct effect on land management practices, economic health and social processes of concern at regional, national and global levels.

N. R. Alibuyog et. al, (2009) predicted the environmental impacts of land use changes in watersheds for developing sound watershed management schemes in Philippine watersheds with agroforestry systems. Model simulation results verified that SWAT can predict runoff volumes and sediment yield with Nash-Sutcliffe Efficiency (NSE) ranging from 0.77 to 0.83 and 0.55 to 0.80, respectively. Simulation of land use change scenarios using the SWAT model indicated that runoff volume and sediment yield increased by 3% to 14% and 200% to 273%, respectively, when 50% of the pasture area and grasslands is converted to cultivated agricultural lands. Consequently, this results in a decrease of baseflow of 2.8% to 3.3%, with the higher value indicating a condition of the watershed without soil conservation intervention.

R. J. Kimwaga et. al, (2012) studied Simiyu catchment of Lake Victoria and used land-uses of 1975 and 2006 and comparing the relative impact of land-use change on sediment loading into the Lake. Remote sensing using the package LIWIS 3.0 was used to identify the land-use while Soil and Water Assessment Tool (SWAT) was used to measure sediment loading from the 1975 and 2006 land-use scenarios. The results of his study indicated that there was an expansion of agricultural land from 19.33% to 73.43% of the catchment at an annual change rate of 2.9%. Moreover, the land-use of 1975 yielded less sediment loading compared to that of 2006. Model simulation at the catchment outlet for sediment reported a total yield of 98,467 tons/yr.

Kigira F.K. et. al, (2010) assessed the impact of the changes in land use and land cover on water and sediment yield on Thika River Catchment. He analysed satellite images of 1987 and 2000 for land cover changes. They used weather and stream flow data for the years 1979-1984 to simulate streamflow and sediment yield using Soil and Water Assessment Tool (SWAT) model. GIS and Remote sensing techniques using Idrisi Kilimanjaro software in evaluating land use and cover changes. The results revealed that the forest cover in the Thika River catchment decreased by 36%, the area under horticultural crops increased by 32% while the built up area expanded by 141%. A 100% forest cover would decrease the current sediment yield by 30%, while a decrease in forest cover of 20% would increase sediment yield by 40%.

M. Minwer Alkharabsheh et. al, (2013) assessed the impact of land cover change on the erosion in agricultural areas of northern Jordan. He achieved it quantifying and analyzing the soil erosion in the study area between the years 1992 – 2009, and by comparing it with land cover changes. The mean soil loss in the study area was 9.53 t/hr and 8.97 t/hr in 1992 and 2009 respectively. The differences in soil erosion risk between the two years were considerable indicating that changes in land cover affects significantly the soil erosion rate.

Wei Ouyang et. al, (2010) used multi-year land use database in Soil Water Assessment Tool (SWAT) for an accurate assessment, from 1977 to 2006, of erosion in the upper watershed of the Yellow River. At same time he introduced the impacts of land use and landscape service features on soil erosion load were assessed. The highest soil erosion load which occurred in 1977, 1996, 2000, and 2006 was 160, 81, 85, and 67 t/ha/y, respectively. The main soil erosion came from agricultural land in the eastern area.

Ji Chen et. al, (2012) investigated soil erosion and identified the most seriously eroded areas in the East River Basin in southern China using Soil and Water Assessment Tool model (SWAT). He derived spatial soil erosion map and land use based on erosion levels that can explicitly illustrate the identification and prioritization of the critical soil erosion areas in this basin. The whole basin was about 24.9 t/ha/yr indicates that subbasins have a larger erosion intensity (about 40 t/ha/yr). The higher soil erosion level in subbasin 20 is due to the high percentage of agricultural land (about 37%).

Andrew K.et. al, (2010) studied the temporal-spatial interaction of land cover status with soil erosion characteristics in the Longliu Catchment of China, using the Soil and Water Assessment Tool (SWAT) model. The SWAT simulation revealed that the annual soil erosion and sediment yield showed similar spatial distribution patterns, but the monthly variation fluctuated significantly. The simulation in this study demonstrates that the erosion loading of bare land is not the highest. Agricultural land had a moderate erosion loading, but the sediment discharge is not comparatively high. The proper tillage practice with the consideration of local environmental feature is conducive to soil conservation.

Seleshi B. A. et. al, (2010) studied the SWAT (Soil and Water Assessment Tool) model to apply in Gumara watershed to predict sediment yield and runoff, to establish the spatial distribution of sediment yield and to test the potential of watershed management measures to decrease sediment loading. The model was calibrated using five year of flow and sediment records and validating using data for the next three years. The installation of vegetation filter strips on vulnerable land was shown to result in 58 to 74% reduction in sediment yield.

Julie Earls et. al, examined applicability of the SWAT model to predict streamflow with varying land use and meteorological data including the ability to predict hydrographs for future land use in Charlie Creek watershed in Central Florida, U.S.A.. He assessed changes over a 20-year period (1980-2000) the occurrence of an identical amount of rainfall in a watershed.

N. Sajikumar et. al, assess the effect of change in land use land cover on the runoff characteristics of a region in general and of small watershed levels (subbasin levels) in particular. Such an analysis can effectively be carried out by using watershed simulation model SWAT with integrated GIS frame work. It is seen that the reduction in the forest area amounts to 60% and 32% in the analysed watersheds. However, the changes in the surface runoff for these watersheds are not comparable with the changes in the forest area but are within 20%. Similarly the maximum (peak) value of runoff has increased by an amount of 15% only.

Bingqing Lina et. al, (2015) Analyses of landuse change impacts on catchment runoff using different time indicators based on SWAT model. Jinjiang, a coastal catchment of southeast China with a humid sub-tropical climate, was used for simulations. A calibrated SWAT model produced satisfactory reproduction of annual, monthly and daily runoff processes over nine year (2002–2010) period at three gauging stations. The results showed the annual runoff had the smallest increase between two scenarios, monthly runoffs had medium rates, and daily runoff had the largest rates with the increase in flood peaks but decrease in drought flows. Indication of different time scales proved appropriate for analysing land use change impacts.

Keith E. Schilling et. al, used the Soil and Water Assessment Tool (SWAT) model to evaluate potential impacts from future land use land cover change on the annual and seasonal water balance of the Raccoon River watershed in west-central Iowa. Three primary scenarios for land use land cover change and three scenario variants were evaluated, including an expansion of corn acreage in the watershed and two scenarios involving expansion of land using warm season and cool season grasses for ethanol biofuel. Modeling results were consistent with historical observations. Increased corn production will decrease annual ET and increase water yield and losses of nitrate, phosphorus, and sediment. Study results indicate that future land use land cover change will affect the water balance of the watershed, with consequences largely dependent on the future land use land cover trajectory.

IV. 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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