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Review Article

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A Review- Impact of land use land cover change and best management practices in a watershed by using swat model

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ABSTRACT

Land use changes are altering the hydrologic system and have potentially large impacts on water resources. Rapid socio-economic development drives land use change. There is an urgent need for technologies and models that can quantify the impact of land use change and management practices in an organized manner. Soil and Water Assessment Tool (SWAT) integrated with Geographic Information System (GIS) has great potential in current estimation, future prediction and proper decision making in terrestrial ecosystems. This review discusses the current utilization of SWAT in impact assessment of land use/cover change and best management practices. Resulted, deployment of SWAT and land use/cover simulation models for impact assessment improves accuracy, reduces costs, and allows the simulation of a wide variety of conservation practices at watershed scale. This review demonstrates the synergistic role of SWAT and GIS technologies in improving watershed management.

Keywords: *watershed, Land, hydrological processes, SWAT.*

INTRODUCTION

Land use planning and management are closely related to the sustainability of water resources as changes of land use are linked with amount of water through relevant hydrological processes. The relationship between land use and hydrology is complex, with linkages existing at a wide variety of spatial and temporal scales. Land cover and use directly impact the amount of evaporation, groundwater infiltration and overland runoff that occurs during and after precipitation events. The effect of the land cover changes and best management practices (BMPs) has impact on the stream flow of the watershed by changing the magnitude of surface runoff and ground water flow. The change in landuse controls the water yields of surface streams and groundwater aquifers and thus the amount of water available for both ecosystem function and human use. While land change is clearly a forcing factor in water supply, it is also an important driver of human water demand and overall water quality. The consequences of all of types of land changes have profound impacts on water quality. Land use change and management plays a significant role in water quality and quantity and there is a great need to integrate land change science, hydrology and water resources management in future research initiatives. Hence, a review on impact of land cover changes on the hydrology of the watershed has been presented in the paper.

Understanding the implications of changes in land cover and land use is a fundamental part of sustainable land planning and development. On one hand, transformation of land cover and land use by human action can affect the integrity of a natural resource system and the output of goods and services of the ecosystem. On the other hand, by careful planning, the development of new patterns of land cover and land use can enhance the well-being of people. Modeling tools have changed the scientific framework for analysis of land use systems, from one that is descriptive to one that is more quantitative which addresses both spatial and temporal dynamics.

Land use changes in river basins result in flooding events that increase sediment load, which is a global concern[1,2,3]. Changes in land cover result in some proportional alterations in the basin condition and hydrological response. This is becoming one of the main contemporary land management issues[4].

The impacts of human activities and climate change on hydrological processes of rivers have been widely studied. In recent years, application of process models has become an indispensable tool to understand the occurrences of natural processes at the watershed scale. Geographic Information System (GIS)-based spatial modeling has become a crucial tool in runoff and soil erosion studies and, consequently in development of appropriate soil and water conservation strategies.

The Soil and Water Assessment Tool (SWAT) model[5] has proven to be an effective tool for assessing water resource and nonpoint-source pollution problems for a wide range of scales and environmental conditions across the globe and over a long period of time[6]. Therefore, this paper aims to review SWAT application for impact assessment of Land Use and Cover Change (LUCC) and Best Management Practices (BMPs) that are related to runoff and sediment analyses. In addition, this paper aims to present an overview on SWAT efficiency analysis and its integration with Land Use and Land Cover (LULC) simulation models.

Theory of SWAT

SWAT can be best suited to agricultural watersheds. It is a river basin scale, continuous time and spatially distributed physically based model to predict the impact of land management practices on water, sediment and agriculture chemical yields in complex catchment with varying soils, land use and management conditions over period of time[5,7]. Hence, SWAT is adopted to model the water resources of a watershed. 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, sediments and nutrients through the channel network of the watershed to the outlet[8]. Each sub basin in SWAT is discretized into a series of Hydrologic Response Units (HRUs), which are unique in soil-land use-slope combinations[9].

Hydrologic simulation of SWAT is based on the water balance equation[8].

$$SW_t = SW_0 + {}^{t}_{i=1} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \qquad (1)$$

where: SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

SWAT provides two methods for surface runoff estimation. The first one is based on the Soil Conservation Service curve number procedure[10] and the second one estimates runoff height using the Green and Ampt infiltration method[11].

Soil erosion caused by rainfall and runoff is computed by the Modified Universal Soil Loss Equation (MUSLE)[12].

$$sed = 11.8 \text{ X } (Q_{surf} \text{ X } q_{peak} \text{ X } area_{hru})^{0.56} \text{ X } K_{USLE} \text{ X } C_{USLE} \text{ X } P_{USLE} \text{ X } LS_{USLE} \text{ X } CFRG \qquad (2)$$

Where: sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm H_2O ha^{-1}), q_{peak} is the peak runoff rate (m^3 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[13] or the Muskingum river routing method[14]. The maximum amount of sediment that can be transported from each segment of the stream is calculated by the simplified Bagnold’s equation[12]. The maximum concentration of sediment (*concsed,ch,mx*) is compared to concentration of sediment in the reach at the beginning of time step, *concsed,ch,i*. Deposition is the dominant process in the reach segment when *concsed,ch,i* > *concsed,ch,mx*, thus net amount of sediment deposited can be calculated. Degradation is the dominant process in the reach segment when *concsed,ch,i* < *concsed,ch,mx*, thus amount of sediment re-entrained can be calculated[8].

Impact of LULC and BMPs analysis by using SWAT

Due to enormous anthropogenic activities on the natural systems of river basins, SWAT application for assessing LUCC and BMP impacts on watershed hydrological status and sustainable development is gaining momentum worldwide. The impact of change in land use and land cover on water quantity and quality can be estimated very well with SWAT. Hernandez[4] found that SWAT could accurately predict the relative impacts of hypothetical land use change in an 8.2 km^2 experimental sub watershed within the San Pedro watershed. Miller[15] also described, simulated stream flow impacts with SWAT in response to historical land use shifts in the San Pedro watershed (3,150 km^2) in southern Arizona and the Cannonsville watershed in south central New York. Stream flows were predicted to increase in the San Pedro watershed due to increased urban and agricultural land use, while a shift from agricultural to forest land use was predicted to result in a 4% stream flow decrease in the Cannonsville watershed. Increased stream flow was predicted with SWAT for the Aar watershed (59.8 km^2) in the German state of Hessen, in response to a grassland incentive scenario in which the grassland area increased from 20% to 41% while the extent forest coverage decreased by about 70% (Weber *et al*., 2001). The impact of hypothetical forest and other land use changes on total runoff using SWAT are presented by Lorz[16] in the context of comparison with three other models.

Pikounis[17] applied the SWAT model to investigate the impact of change in land use on hydrology in the Ali Efenti catchment (2976 km^2) of the river Pinios in Thessely Greece on a monthly step. Three land use change scenarios are examined, namely (A) expansion of agricultural land, (B) complete deforestation of the Trikala sub-basin and (C) expansion of urban areas in the Trikala sub-basin. The deforestation scenario has resulted in the greatest alteration of total monthly runoff. SWAT was used by Afinowicz[18] to evaluate the influence of woody plants on water budgets of semi-arid rangeland in southwest Texas. Baseline brush cover and four brush removal scenarios were evaluated. Removal of heavy brush resulted in the greatest changes in ET (approx. 32 mm $year^{-1}$ over the entire basin), surface runoff, base flow and deep recharge. Lemberg[19] also described brush removal scenarios.

Saadati[20] applied SWAT to simulate the effect of land use on surface runoff in the catchment. The model simulated the stream flow under positive and negative land use scenarios successfully. There was increase in runoff when existing forest and range land has been converted into cultivated land. Further, it was also noticed that increased runoff was simulated when forest land alone has been converted into cultivated land. The effect of land use change on sediment yield of the Arachtos catchment (2000 km^2) in west Greece was simulated by SWAT[21]. The maximum discharge at sub basin became 1200m^3/sec, if total precipitation increased by 20% and it became 2.1 m^3/sec if the amount has been reduced by 20%. The model successfully predicted the influence of crop rotation and special cultivation techniques on the parts of the agriculture land to erosion. Winter wheat cultivation under strip cropping system resulted in the highest annual reduction of sedimentation rate in the Pournari reservoir from 3.80 Mt/y to 3.04 Mt/y due to minimizing P_{USLE} value from 1 to 0.30.

The hydrological modeling of Biobio river basin (24,371 km^2) in the Chile under conditions of limited data availability was carried out by SWAT[22]. The potential impact of land use and climate changes on basin in the Vergara sub-basin of Biobio basin was quantified. Zhi Li[23] used the SWAT model to evaluate the effect of land use change and climate variability on hydrology for the Heihe river in the Heihe catchment (1506 km^2), China from 1981 to 2000. The SWAT model was simulated with four scenarios based on two time scales of meteorological data, 1981 to 1990 and 1991-2000 and two land use maps of 1985 and 2000 to represent the land use patterns of 1980s and 1990s respectively. Compared with scenario 1 (1985 land use and 1981-1990 climate), the simulated runoff was (2000 land use and 1991-2000 climate) decreased by 27.6 mm, which represented the combined effect of land use change and climate variability. Similarly changes in land use over time scale and its impact on stream flow was studied by Faith[24] in the river Nzoia catchment, Kenya. In a case study at the Little Miami Watershed, USA, it was recognized that as the land use in the watershed shifts from predominantly agricultural to mixed rural and residential lands, a significant reduction in flow, sediments, and nutrients is detected[25].

The SWAT model was also used to simulate the main components of the hydrological cycle, in order to study the effects of land use changes in 1967, 1994 and 2007, in the Zanjanrood Basin, Iran[26]. The results indicated that the hydrological response to overgrazing and replacement of rangelands with rain-fed agriculture and bare ground was nonlinear and exhibited a threshold effect. The runoff rose dramatically when more than 60% of the rangeland was removed.

Yacob[27] applied the SWAT model to identify the effect of land use and land cover change on runoff and sediment in Tikur Wuha watershed (706 km^2) of Ethiopia. The model predicted a strong relation between water yield and land use change during the calibration. Higher value of the surface runoff correlated with orthic luvisols soil type and bare and open shrub land use was observed. Mango[28] explored the impact of LUCC on SWAT outputs, mainly on the discharge of the Nyangores River. They developed three land use scenarios, namely 1) partial deforestation, conversion to agriculture, 2) complete deforestation, conversion to grassland, and 3) complete deforestation, conversion to agriculture. The results of the analysis indicated that conversion of forests to agriculture and grassland in the basin headwaters reduced dry season flows and increased peak flows, leading to greater water scarcity at critical times of the year and exacerbating erosion on hillslopes. In another application of SWAT, hydrological modeling was conducted for each of the land use map in four time periods (1973, 1986, 1992, and 1997) in the upper San Pedro watershed, USA[29]. Results demonstrated that urbanization and mesquite invasion were the major environmental stressors affecting local water resources. Elsewhere, five scenarios of land use change were evaluated in the Chi River basin, Thailand[30]. These scenarios are included of a conversion of forested area, expansion of farmland, switching of rice paddy fields to energy crops and two scenarios involving conversion of farmland to rice and sugarcane plantation. Conversion of forested area and farmland showed small changes on water flows and evapo-tranpiration (ET). Substitution of paddy fields by sugarcane plantation clearly resulted in reduced water flows and increased ET in the dry season. Particularly, in the case of expansion of rice paddy fields to farmland, small changes occur on annual flow and ET but more significant effects occur on seasonal flows. The results showed decrease in ET, leading to increase of water yield during the dry season. The conversion of farmland to sugarcane plantation for biofuel production showed a significant effect on seasonal ET, but small changes on water yields.

Wenming[31] used the SWAT model to assess the impact of Land use and land cover changes on hydrology for the upper San Pedro watershed (7400 km^2) in Mexico. An integrated approach of hydrological modelling and multiple regression analysis was adopted to quantify the contribution of changes of individual LULC classes on changes in hydrological components for four time periods (1973, 1986, 1992, and 1997). Urbanization and mesquite invasion increased runoff, reduced percolation and increased ET, which have a negative impact on water resources in the upper San Pedro River Basin. Compared to the LULC baseline in year 1973, the average annual water yield over the watershed is 0.07 mm higher in 1986, 0.13 higher in 1992, and 0.25 mm higher in 1997 (increasing 1.9%, 3.5%, and 6.8% respectively). Friedrich[32] adopted SWAT model to investigate the effect of dynamic land use on daily discharge, the total annual runoff and peak flow by adding "Land use Update and Soil Assessment" (LUPSA) in order to improve the overall SWAT abilities to handle land use changes in the Gedeb catchment (290 km^2), Ethiopia. LUPSA was applied during the period of 1973 to 2003 with yearly land use updates. The annual LUC varied between -6% and +360% for different classes. There was a significant difference in the total discharge volumes observed which accounts for 2.9% of the total flow within the whole period of 30 years. Cai[33] investigated the impact of land use change on the sediment yield characteristics in the upper Huaihe River, China, using land use maps over three phases, i.e. 1980s, 1990s and 2000s. Results revealed that under the same condition of soil texture and terrain slope, the increasing rate for sediment yield and the sensitivity of rainfall–sediment yield relationship to rainfall alterations descended by woodland, paddy field and farmland.. Glaven[34] used historical land use maps from 1787, 1827, 1940 and 1984 and a 2009 land use map depicting present situation for LUCC impact assessment of two small scale Slovenian watersheds. Results showed that for both watersheds the influence of land use change on total and green water quantity would be statistically insignificant but would have considerable effects on the seasonal flows.

Girolamo and Porto[35] applied SWAT to develop possible land use and land management scenario that could constitute an alternative to the current watershed management in the Rio Mannu River Basin (Sardinia, Italy). The replacement of durum wheat with rapeseed (biofuel crop), could offer a margin of profit, but would have a negative impact on water quality due to increased nutrient losses. Further more, it can be inferred that promotion of the use of energy from renewable sources may have a negative impact on the objectives of the EU water framework directive. Three land use scenarios with climate change scenarios were considered in investigating the impact of land use change on streamflow and sediment yield in the Be River Watershed, Vietnam[36]. In the first scenario, all current shrubland were converted into perennial cropland, and the remaining land use types were kept constant. The second scenario assumed that all productive forest land will be replaced by shrubland. Using the third scenario, all shrubland and productive forest land were replaced by perennial cropland. Generally, the separate impacts of climate and land use changes on streamflow, sediment load, and water balance components were offset by one another. However, surface runoff and few components of subsurface flow were more sensitive to land use change than to climate change. Furthermore, the results emphasized water scarcity during the dry season and increased soil erosion during the wet season. Mueller[37] adopted the SWAT model for Calapooia River Basin in Western Oregon to model the effect of land use changes on water yield and quality from 2003 to 2007. By modifying the agricultural management practices and grain seed crops under different land uses from current eight crops to fifteen new crops scenario, there was not much change in total water yield (55.118 cm to 65.786 cm). However, the yield has been changed with the change in climate. Nie[29] applied the SWAT model to assess the hydrological consequences of Mesquite tree encroachment in the Upper San Pedro watershed (7400 km^2), Mexico by implementation of different changes in land use. The results indicated that complete replacement of grassland with mesquite increased the simulated annual average basin ET from 384.3 to 386.1 mm and decreased the annual average basin runoff from 2.66 to 2.35 mm.

The effect of different land uses on the water yield of the Kothakunta sub-watershed in India (550 ha) with varying soils, land use and management conditions over long period of time was quantified by SWAT[38]. Zhang[39] generalized the characteristics of the human activities to predict future runoff using climate change scenarios, in the Biliu River basin, China. Results showed that future annual flow will increase by approximately 10% from 2011 to 2030 under normal human activities and future climate change scenarios, as indicated by climate scenarios with a particularly wet year in the next 20 years.

Shao[40] in studying the Laurentian Great Lakes Basin, USA, considered two future agricultural scenarios compared with the current baseline condition, which includes conversion of all ‘‘other’’ row crop types to corn and hay/pasture to corn. Results revealed significant increases in average annual sediment yields compared with the baseline condition. Yan[41] used the SWAT model to assess the impact of land use change on watershed stream flow and sediment yield for the Upper Du watershed (8973 km^2) in China. An integrated approach involving hydrological modelling and partial least squares regression (PLSR) was employed to quantify the contribution of changes in individual land use types to changes in stream flow and sediment yield. The results indicated that changes in grassland did not show a significant influence on either stream flow or sediment yield.

BMPs are techniques, measures or structural controls that are used for a given set of conditions to manage the quantity and to improve the quality of runoff water in the most effective manner. Arnold and Allen (1996) used the SWAT model to simulate the major components of the hydrological budget in order to determine the impact of proposed land management, vegetative changes, ground water withdrawals and reservoir management on water supply and water quality in the three watersheds namely, Panther Creek (246 km^2), Goose Creek (122 km^2) and Hadley Creek (188 km^2). The results helped to formulate appropriate land use management practices on basin wide scale. The influence of BMPs on quantity and quality of water can be assessed effectively by SWAT. Kirsch[42] described SWAT results showing that improved tillage practices could result in reduced sediment yields of almost 20% within the Rock River in Wisconsin, USA. Chaplot[43] found that adoption of no tillage, changes in nitrogen application rates, and land use changes could greatly impact nitrogen losses in the Walnut Creek watershed in central Iowa, USA. Tripathi[44] applied the SWAT model for the critical sub-watersheds of Negwan watershed (92.46 km^2) in India, on a daily and monthly basis to estimate runoff and sediment yield for developing the management scenarios. The predicted values for daily runoff and sediment yield using generated rainfall compared well with observed runoff and sediment yield during 1996-1998. The impact of different agricultural management practices (tillage) on runoff and sediment yield in the critical sub-watersheds was successfully simulated. The use of zero tillage, conservation tillage and field cultivar reduces the sediment yield by 19%, 11% and 10% respectively when compared to the conventional tillage (13.47 t/ha).

Beaudin[45] applied SWAT model for the calibration and validation of runoff and sediment yield and evaluated the impact of Best Management Practices for the Pike River watershed (630 km^2). Mazdak Arabi[46] applied the SWAT model for the analysis of uncertainty in the evaluation of watershed management practices like grassed waterways, grade stabilization structures, field borders and parallel terraces on water quality in the Black Creek watershed located in northeast Indiana in the upper Maumee river basin. The analysis specifically recognizes the significance of the difference between the magnitude of uncertainty associated with absolute hydrologic and water quality predictions and uncertainty in estimated benefits of best management practices. By the implementation of BMPs (scenario A) in the Dreisbach watershed (6.23 km^2) there is a reduction of stream flow about 9.8% from 0.041 to 0.03 7 m^3/s when compared with the scenario B without BMPs. Analysis of BMPs by Vache[47] for the Walnut Creek and Buck Creek watersheds in Iowa indicated that large sediment reductions could be obtained, depending on the choice of BMP. Bracmort[48] showed results of three 25-year SWAT scenario simulations for two small watersheds in Indiana, USA where the impacts of no BMPs, BMPs in good conditions, and BMPs in varying conditions are reported for streamflow, sediment, and total phosphate. Nelson[49] reported that large nutrient and sediment loss reductions occurred in response to simulated shifts of cropland into switchgrass production within the 3000 km2 Delaware River basin in northeast Kansas, USA.The water yield of watershed was simulated by reducing area under paddy cultivation by 25% and allocating that area for irrigated dry crops in order to assess the total aquifer recharge/precipitation ratio and finalized the alternate cropping system for sustainable ground water resources. Phomcha[50] used the SWAT model to identify an effective soil conservation treatment and to minimize sediment yield in the Lam-Sonthi watershed (357 km^2) in central Thailand. The results revealed that the combination of afforestation and mulching was the most effective treatment in reducing sediment yield in the watershed. Kang[51] incorporated a modified impoundment routine into SWAT, which allowed more accurate simulation of the impact of paddy fields within a South Korean watershed. Mishra[52] reported that SWAT accurately accounted for the impact of three check dams on both daily and monthly stream flows for the Banha watershed (17 km^2) in northeast India.

The efficiency of flow diversion terraces (FDT) on maintaining surface water quality at the watershed level in the Black Brook watershed (BBW) in north western Brunswick was assessed by Yang[53]. The SWAT performed well in predicting seasonal variation of water yield and moderately well for sediment yield (R^2 = 0.5). The SWAT model resulted that FDT implemented in BBW contributed to the reduction of sediment yield by 4 t/ha on average, which represented a reduction of 20% during the summer growing seasons.

Huges and Mantel[54] studied the uncertainty associated in obtaining information regarding abstractions from reservoir, dam and its impact on simulating the hydrology of catchment. Welderufael[55] used the SWAT model to assess the impact of rainwater harvest on water resources of the upper Modder river basin, central region of South Africa. The simulated stream flow was highest in the Agri-CON land use (18 mm), followed by PAST (12 mm) and AGRI-IRWH land use (9 mm). Although there was observable impact of rainwater harvesting technique on the water yield when considered on a monthly time frame, the overall result suggested that the annual water yield of one of the upper Modder River Basin quaternary catchment will not be adversely affected but the Agri-IRWH land use scenario despite its surface runoff capture design.

The wide range of SWAT applications in different watersheds with various climatic and land cover conditions described in this paper highlights that SWAT is a very flexible and robust tool that can be used to simulate a variety of land management problems. The process of configuring SWAT for a given watershed has also been greatly facilitated by the development of GIS-based interfaces, which provide a straightforward means of translating digital land use, topographic, and soil data into model inputs. Additionally, development of new facilities for SWAT auto-calibration and uncertainty analysis has presented a new era in SWAT application for LUCC and BMP simulation with the highest possible accuracy.

CONCLUSIONS

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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