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Soil and Water Assessment Tool Application in Natural Resources Management: A Systematic Review

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ABSTRACT

There has been continuous research in the field of hydrology as there is tremendous change in climate and land use happening due to anthropogenic activities for decades now. These human activities are taking toll on natural habitats and ecosystem as development is speeding day by day. To assess these various impacts, the hydrological modelling can see as a watershed moment, these models are to incorporated to assess the impacts of these practical issues as well as planning, design and management for mitigation in future. The distributed hydrological models i.e., soil and water assessment tool has been in use and become a focus in hydrological studies. This paper analyses the progress in hydrological modelling using SWAT through previous literatures briefly. The research with the help of SWAT model has been carried out to assess number of hydrological phenomenon and through various fields of study. SWAT model has been used in many studies from streamflow studies to land use planning studies with very effective application which can be seen from the reviews that has been studied in this paper. Therefore, this paper mainly focuses on studies by various researchers with the application of Soil and Water Assessment Tool. This review will give insights about role of SWAT in natural resources management and integrated watershed management.

HIGHLIGHTS

- Soil and Water Assessment Tool (SWAT), a hydrological model is used around the world for mitigating problems related to natural resources management especially environmental problems such as runoff and sediment yield analysis, land use and climate change impacts and future management etc.
- The reviews mentioned below suggests that SWAT model can be used for any climatic condition and with inadequate data availability for different sizes of watersheds.

Keywords: Soil and Water Assessment Tool, hydrological modelling, Natural resources management

Natural resources management plays very vital role in agriculture of any national economy especially developing countries like India. It should be aim of every farmer, large scale farm managers and agriculture agencies to make production of food in cost effective manner. This can be possible only with the sustainable management of natural resources such as soil, water in effective manner (Rakshit *et al.* 2017). There has been advances in technology in recent decades which has been proved to be very important technology for natural resources management.

Hydrological modelling is such a technique which mainly includes empirical, conceptual and physically based models. There have been further two types in which conceptual models are divided such as lumped models and distributed models. In last decades, there has been advances which has led to climate change due to anthropogenic activities, ill effects on surrounding environment, more extreme nature of rainfall and temperature etc. The lumped models are not capable of reflecting the changes due

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to spatial differences in runoff and nutrient flows effectively (Jiang *et al.* 2017; Wang *et al.* 2019). But in case of distribute models, it divides the whole catchment area into number of sub-watersheds of smaller size which gives the final simulation result much closer to actual results. The distributed hydrological modelling can effectively show the spatial and temporal hydrological processes; therefore, it has more significance in development utilization and management of natural resources in very effective manner.

One of the distributed models that has been in practice by many hydrologists, civil engineers, researchers across India as well as throughout the world which is Soil and Water Assessment Tool (SWAT). SWAT utilizes many hydrological factors while simulating the hydrological processes happening in the catchment of river basins. It basically operates on daily time scale and it has applications in impact assessments on soil and water due to management practices. There have been numerous applications of SWAT from few kilometres of watershed to thousands of kilometres of watersheds in the world. It has been utilized for hydrological research such as streamflow and sediment simulations from gauged or ungauged watersheds, water quality assessments, land use impact assessments by many researchers worldwide.

The main objective of this paper is therefore to review the research that have been carried out with the help of Soil and Water Assessment Tool in the field of hydrology and natural resources management for effective management of natural resources for sustainable future.

Soil and Water Assessment Tool Description

SWAT model is basically a continuous time scale, watershed scale and semi-distributed model and it has been developed by the USDA Agriculture Research Service (USDA-ARS). The impact of land use and management on natural resources such as water and soil chemical yields from the agriculture areas etc. is the main area for which SWAT has been designed (Arnold *et al.* 1998). The land phase and channel phase are two phases into which the simulation processes in the SWAT distributed model. In case of land phase, it mainly has control on the entering of water, sediments, nutrients and chemicals from the smaller sub watersheds into the main channels in the watershed. The channel phase basically involves the processes of transferring water, sediment and nutrients or chemicals from these networks of channels into the basin**.** The hydrological cycle process includes hydrology, weather, sediment, soil temperature, plant growth, nutrients, pesticides or chemicals and agricultural management from the sub-watersheds (Arnold *et al.* 1998; Douglas-Mankin *et al*. 2010)

According to the law of water balance, SWAT model water balance can be seen in the form of following equation:

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

where SW_t is the final water content of the soil, SW_0 is the water content in the early stage of the soil, t is time in days, R_{day} is the daily precipitation, Q_{surf} is the daily surface runoff, E_a is the daily evapotranspiration (*ET*), W_{seep} is the daily percolation, Q_{gw} is the daily return flow, all units are in mm.

Due to distributed nature of SWAT model, not only it is divided into sub watersheds but sub watersheds are further divided into Hydrologic response units called HRUs of similar soil, land use conditions in order to improve accuracy of model simulation. The data that is required for model set up is watershed Digital Elevation Model (DEM), land use map, soil type and soil attribute table, meteorological data, observed parameters etc. The evaluation of model simulation results is carried out using the regression correlation coefficient (R^2), Nash-Sutcliffe modeling efficiency (NSE) and relative error (Re) (Krause, Boyle, and Base, 2005). Generally, it is accepted that if $R^2>0.6$, $NSE>0.5$, $|Re|<20\%$, then the SWAT model meets the criteria and therefore, is suitable to simulate the watershed.

Soil and Water Assessment Tool for Quantification of Runoff

Estimation of surface runoff which water flowing from the surface of land in the direction of slope is very necessary for many water quality measuring projects. Surface runoff influences, flooding, aquatic life, stream geomorphology, also streamflow mainly has impact on power generation, transport and delivery of many pollutants. The quality and quality of pollutants can be studied only by measurement of flow of water or the source. This quantification of water flow is done by hydrological models i.e., SWAT. There have been many studies around the world and numerous watersheds for which the model has been utilised for the surface runoff, streamflow simulation.

The SWAT model has been utilized for plain regions to mountainous region around the world. Shawul *et al.* (2013) used SWAT model in Shaya watershed which is situated in south-eastern part of Ethiopia in Genale-Dawa basin in order to do estimation of monthly and seasonal water yield at the outlet of this watershed to understand the quantity and quality in space and time. The model has shown quite good results for the area as coefficient of determination of 0.71, the Nash–Sutcliffe simulation efficiency (ENS) of 0.71 and percent difference (*D*) of 3.69, for calibration and 0.76, 0.75 and 3.30, respectively for validation. The calibrated model has estimated mean monthly and annual water as 25.8mm and 309.0 mm respectively. The attempt has been made by Tang *et al.* (2012) in Chao River basin as basin is facing water scarcity due to human activities and climate change. The calibration period taken for the study was from 1995 to 1999 and the p-factor and r-factor found was 0.85 and 1.12. Similarly for validation period of 2000-2002, the p-factor was found to be 0.83 with the r-factor of 2.15. R^2 and NSE were also found in good range, for calibration R^2 was found 0.90 and NSE was found 0.88. For validation R^2 was found 0.77 with NSE of 0.74, giving satisfactory results. Another study similarly used SWAT model by Santra and Das (2013) in Chilka lake which is biggest lagoon in Eastern Coast**.** The runoff predicted was on monthly basis, with 0.72 for calibration and 0.88 for validation. It is also found that 60% of the rainfall has been contributing the runoff from the Chilka lake watershed, which carries significant amount of soil to the lake.

Sahu *et al.* (2016) made an attempt of modelling hydrology of Mahi River basin, India in order to evaluate the suitability of SWAT model in predicting streamflow as well as analyzing the uncertainty. The observation points used in the study were total five with four of them showing good NSE and R^2 of the simulated model. SWAT model has been used in Tapi Basin in the Anjana Khadi Watershed to evaluate the runoff potential from the basin (Patel and Nandhakumar (2016). It was found from the model simulation that the maximum water potential was from WS22 with least for WS25 watershed. This paper indicates the SWAT is an efficient tool for modeling and to simulate the runoff potential from the area. The literature reviewed indicates that the adoption and adaptation of SWAT to these diverse environmental and climatic conditions is definitely promising tool.

Soil and Water Assessment Tool for Sediment Yield Simulation

The most important and essential gift that nature has provided for human beings is soil (Singh and Saika, 1990; Singh 2002). The ecosystems provide human with services and many goods in which soil plays important role in obtaining those goods and services. Major nutrients such as carbon, nitrogen, phosphorous etc. are provided by soil and it has major role in the supporting the life on earth. Soil has importance in agricultural purpose, forestry and pastoral production. Soil not only contributes to production of goods but also has importance in controlling emissions of greenhouse gases and carbon sequestration so that climate can be regulated. Meanwhile, soils are always faced with challenge of soil erosion where most productive layer of surface soil gets eroded due to high intensity rainfalls and slopes. This problem has become so critical that it has impact on environmental, ecological and economic balance. This problem has been checked by models in last decades, as they can predict reliably good quantity of sediments and rate of transport into streams, rivers and water bodies. These models are very good in identifying erosion prone areas from watershed and propose necessary management practices in order to reduce the impact of soil loss. There have been many attempts made by numerous researchers in the field of sediment assessments and management practices.

Assessment for sediment yield in Northern Morocco for Kalaya gauged watershed is carried out with the help of SWAT model (Briak *et al.* 2016). SWAT model has been simulated for the years 1973 to 1993 with calibration for monthly time step. Model has shown good performance for sediment concentration with NSE of 0.76 and PBIAS pf -11.80 for the 1976 to 1984 calibration period and 0.69, 7.12 respectively for validation period of 1985 to 1993. It is evaluated that the soil loss from the study watershed varied from 20 to 120 t/ha/yr with effective hydraulic conductivity, USLE support practise factor and Manning's roughness coefficient as the most sensitive factors for the study area. Ayana *et al.* (2012) applied SWAT model in Fincha Watershed (3252 km^2) located in Western Oromiya state, Ethiopia. The results for the model for calibration period (1987 to 1996) showed good performance with monthly sediment yield R^2 as 0.82 and NSE as 0.80. The validation period (1997 to 2006) results were also found satisfactory with R^2 of 0.80 and NSE of 0.78. So, study showed that model was quite good in predicting sediment yield from the area and it can be used as necessary management planning tool for future in the study area.

Reservoir sedimentation has become critical issue to large quantity of sediment transport from highlands into the reservoirs rapidly decreasing their storage capacity throughout the world. The attempt has been made for assessment of sediment inflow into the Somerville reservoir, Texas, USA with the SWAT model (Djebou, 2018). The performance parameters showed good results as NSE was found between 0.69 to 0.76. The main point that study showed was that there were subbasins with critical need for soil conservation having soil losses more than 4 t/ha/yr. Therefore, it is seen that SWAT is very valuable for complex problems like sedimentation for reliable future management. In India SWAT model was applied in Nagwa watershed to assess its ability to simulate sediment yield as well as uncertainty along with it (Singh *et al.* 2014). The monthly sediment yield prediction during the whole calibration and validation period was in close agreement with its observed values. It was found that the observed and simulated sediment yields as indicated by values of R^2 of 0.78 and 0.68, and NSE values of 0.76 and 0.66, respectively was quite good performance. Mamo and Jain (2013) used SWAT model for assessment of sediment in Gumera catchment, Ethiopia where model was calibrated for the period of 1994 to 2002 and validated for period 2003 to 2006. The monthly sediment yield was simulated and its performance assessment showed valid results with R^2 and NSE as 0.61 and 0.60 for calibration period and 0.84, 0.83 for validation period, respectively. After reviewing these studies, it can be seen that model has quite good applicability in the field of sediment yield predictions. SWAT Model has shown good results in sediment yield assessment studies throughout the world with versatile ecological, environmental conditions. Therefor, as a precious natural resource of mother nature, the soil loss prediction using SWAT can be seen as a good advancement in the hydrological studies.

Land Use Land Cover Change Impact and Soil and Water Assessment Tool

Land use / land cover changes have occurred throughout the for at least four decades with devastating speed leading to major economic, social and environmental impacts. The main backbone for agricultural economics is land use and land cover as it provides with vast benefits. Urbanization for decades now, presented farmers with very challenging task of sustainable farming in order to provides food without damaging future. Although without these economic and social progress is very difficult to achieve. There have been substantial changes in the world due to deforestation, agricultural and urban development and other human developmental activities. This land use land cover changes needs to be addressed. This task of addressing the challenges of land use land cover impacts has been addressed with hydrological modelling. There have been many studies where impacts of land use land cover have been addressed with the help of many hydrological studies. The soil and water assessment tool, one of the hydrological models which have been used by researchers, hydrologist to study the impacts of decadal changes of land use land cover as well as future implications of them.

There have been studies which investigated impacts of land use changes on runoff and sediment yield with the help of SWAT model. Githui *et al.* (2009) used SWAT model in the catchment of Noiza River, Kenya. The model has been calibrated for daily discharge in the catchment and land use cover impacts have been addressed for the same. The land use scenarios developed where it was observed that in between the years 1973 and 2001, the agricultural area has increased from 39.6% to 64.3%, however the forest has been decreased from 12.3 % to 7.0 %The surface runoff has difference of 55 to 68% when the comparison was done between 1970-1975 and 1980-1985. Similarly, there has been study by Kavin *et al*.

(2018) where assessment of land use land cover on the runoff as well as nitrate loads was done with the help of SWAT model in the Talar river (northern Iran) in between 1991 and 2013. The results showed that forest area was decreased and irrigated crops, agricultural lands, range lands, urban area have increased. The forest area was decreased up to 14.9 % with 46.8% increase in the irrigated areas in the study area. This has major impacts on the runoff as well as nitrate loads increased by 34.4% and 42.2% in 1991–2013. Therefore, such hydrological modelling techniques were found quite valuable in preparation of maps and assessing future implications as it was found that the simulation for the years 2013-2050 runoff and nitrate loads increased by 42.3% and 55.9% from all the sub-basins.

Hydrological response of land use land cover changes in the Tekeze watershed, Northern Ethiopia was assessed (Welde *et al*. 2017), where three scenarios (climate of 2000s & 2008 LULC, climate of 2000s & 1986 LULC and climate of 1980s & 1986 LULC) were used. The positive impacts observed in the study area was that there has been transition of grass and shrub land into agricultural land. The results showed that mean annual stream flow was increased by 6.02% (129.20–137.74 m^3/s) and sediment yield amounts to an increase of 17.39% (12.54–15.18 t/ha/yr) owing to increasing bare land and agricultural areas. Another study was carried out by Zhang *et al*. (2019) used SWAT in the Hun River Basin (HRB) with area of 7919 km^2, Northeast China. It was found from the study that the monthly runoff and sediment yield was simulated satisfactorily. Due to forest area sediment yield was reduced, percolation was increased as well as runoff was reduced, grassland also had similar effects as that of forest land. However, cropland increased runoff and increased sediment yield and opposite was the case of urban area with higher sediment for light rain. Similarly, the objectives of the study by Hajihosseini *et al.* (2020) were such that impacts of land use changes and climate change in Middle Helmand Basin (MHB) of Afghanistan are studied. In this study land use changes for three periods between 1990 and 2011 has been calculated and its effects on hydrological response of watershed was investigated. Majorly, it was found that there was major change in irrigated area between 1990 to 2011 giving 62% increase in irrigated area from 103,000 ha in 1990 to 167,000 ha in 2011. It was found that due to increase in agricultural activities with decrease of discharge about 346 MCM/year with increase in irrigated area after 1990. Therefore, SWAT was helpful to quantify the impacts of land use changes in the region. It is evident from many studies that SWAT model can be of very help in case of studies related to land use land change impact as it can be seen from the studies highlighted above and many more.

Soil and Water Assessment Tool with Climate Change Impact Studies

Recently, due to more emissions of green house gases, there have been changes in hydrological conditions. There has been rise in global temperature, rainfall patterns are affected, more runoff and sediment transportation, snowmelts, extreme conditions of climate like flood and drought. This had additional pressure on the water resources and further it is affecting hydrology on the global scale. It has become necessary task to prevent the climate change before it is going to affect the future of mother earth. Therefore, climate change studies are vey important. These studies have become possible with hydrological modelling techniques. SWAT model have been used by many scientists, researchers, hydrologists for studies relate to climate change on global basis.

There is study undertaken by Chanpati *et al.* (2020), they have assessed the impact of climate change on the water resources in the Warangal district of Telangana, India. The crop yield gets affected if climate have been altered which automatically affects human significantly. In the study SWAT model have been used for the climate change assessments. The streamflow data of akeru watershed have been utilized for the study and it is found that the results of statistical parameters were quite good with R^2 and NSE values 0.72 and 0.84 for calibration, respectively) and validation periods (0.7 and 0.56, respectively). Model was run for historical and future scenarios for four RCMs (early, mid, and end of the 21st century). There is predicting that an increase in the extremity of rainfall events for the mid and end of the 21st century, especially in the months of July and August. With decreasing trend of crop yield, having more emphasis on future of production of cotton in the district.

Another study Puno *et al. (2019)* predicted the impacts of climate change on the hydrological response of Muleta Watershed in Bukidnon, Philippines using Soil and Water Assessment Tool. Statistical tests with R^2, NS, and RSR values of 80, 0.80 and 0.45, respectively showed very good results for calibration and for validation, acceptable statistical results of R^2 = 0.79, NS = 0.67 and RSR = 0.57. It was found that there has been decrease in runoff and increase in evapotranspiration after conversion of shrubland to forest. Direct influence of the decrease of rainfall by 13% from 2050 PAGASA projection on hydrologic processes. Therefore, it was found that climate and land cover changes negatively affected the study area. Furthermore, one of the studies by Abbas *et al.* (2017) assessed impacts of climate change in Greater Zab and Lesser Zab Basins, Iraq by using SWAT model in order to see impact on water resources. SWAT was applied for near future (2049-2069) as well as in distant future (2080-2099). Six general circulation models (GCMs) with (RCPs) RCP 2.6, RCP 4.5, and RCP 8.5 for periods of 2049-2069 and 2080-2099 were used in the study. It was found from the findings that the basins might undergo alterations due to climate change, and most likely for the worse with decrease in available water.

Hyandye *et al.* (2018) carried out study in Ndembera river watershed in Usangu basin, Tanzania using SWAT model to assess the impact of near future (2010–2039) climate. It was found that there would be moisture balance change with warmer near-future mean annual temperatures (1.1°C) and wetter conditions (3.4 mm/year), which will increase evapotranspiration and decrease water yield by approximately 35 and 8%, respectively. It was also found that the management practises such as filter strips can affect ET and stream flow significantly with reducing the annual evapotranspiration by 6%, and increase stream-flow by 38%. Therefore, future has less available water than present due to climate and land use change.

For instance, an evaluation of the impacts of climate change on water yield was conducted by Villamizar *et al*. (2018) in Tona watershed is situated in the northeast side of Colombia. The study showed impacts of different land use and climate scenarios using hydrological model known as the Soil and Water Assessment Tool (SWAT) model. The results of historical conditions (1987–2002) compared with 2006-2050 giving global estimates of water yield for further strategies. Therefore, hydrological modelling using SWAT was found to be very reliable way of estimating future of water resources for careful planning.

Soil and Water Assessment Tool for Watrshed Priortization and Management

Sedimentation has become serious problem affecting fertile soils for crop production, reservoir capacity affecting, therefore it was very necessary to identify exact locations of sediment losses. Exactly knowing the locations of the soil erosions, the management can be strategized and actions can be taken as time and money can be manged accordingly without excessive wastages. SWAT is such a hydrological model which has been used by many researchers for the identification of soil erosion or water eroded sites.

Soil and Water Assessment Tool used by Welde K. (2016) in the Northern Ethiopia for the identification and prioritization of subwatersheds for land and water management for Model calibration (for the period of January 1996 to December 2002) and validation (for the period of January 2003 to December 2006). It was found that the watershed has mean annual stream flow of 137.74 m3/s and annual sediment yield of 15.17t/ha/year with total 13 watersheds out of 47 fit for prioritization. Maximum sediment loss was ranged from ranges from 18.49 to 32.57 t/ha/year with average land slope ranging from 7.9 to15.2% dominated by cultivated land, shrub land & bare land. Dibaba *et al.* (2021) used SWAT model giving reliable results such as coefficient of determination (R^2), Nash–Sutcliffe efficiency (NSE), and percentage bias (PBIAS) as 0.59, 0.57, and −0.9, respectively, and the respective values for the validated model were found to be 0.72, 0.71, and 6.9 for the Fincha catchment, Ethiopia. The average annual sediment yield (SY) was 36.47ton ha^{-1} yr^{-1} with the annual yield varying from negligible to about 107.2 ton ha^{-1} yr^{-1} in Finchaa catchment for the period 1990–2015. About 24.83% of the area from five subbasins were predicted to suffer severely from soil erosion risks, with SY in excess of 50 ton ha^{-1} yr^{-1}. Only 15.05%. The study showed that SWAT was successfully used for identifying the critical sub-basins in a watershed with imprecise and uncertain data for management purposes.

Kumar *et al.* (2015) used SWAT semi distributed model to identify critical erosion watersheds in Damodar catchment and improving reservoir useful life. It was found that simulated sedimentation rate is 1.12 and 3.65 Mm^3/year, respectively, for Konar and Panchet reservoirs for the studied period (1997–2001). There was reduction in sedimentation rate as the rate was 0.98 and 1.80 Mm^3/year after conservation applied increasing usedful life of 8 and 85 years, respectively for Konar and Panchet reservoirs. Therefore, it was very successful implementation of measures with incorporation of SWAT model. Pandey *et al.* (2021) used SWAT model successfully for the Tons river basin, India for critical area identification with future climate change analysis. It was found that model was calibrated and validated with quite good results of coefficient of determination (R^2), Nash–Sutcliffe efficiency (NSE), percent bias (PBIAS), and root mean square error (RMSE)- observations standard deviation ratio (RSR) was 0.71, 0.70, −8.3, and 0.54, respectively during the calibration period, whereas for validation the values were 0.72, 0.71, −3.9, and .56, respectively. It was further found that in future for the years s 2031–2050 and 2081–2099, respectively the sediment yield annually might increase from baseline 6.85 Mg ha^{-1} to 8.66 Mg ha^{-1} and 8.79 Mg ha−1 respectively. Sub-watersheds, namely SW-8, SW-10, SW-12, SW-13, SW-14, SW-17, SW-19, SW-21, SW-22, and SW-23 were most affected in need of management in the study area. The management practice or measure of recharge structure was found effective giving m reduction of sediment by 38.98% during the baseline period, and a 37.15% reduction in the future scenario. Therefore, from the above studies it was found that SWAT model can be used for assessing the effect of land and management practices on the hydrological response of catchment and identifying the locations that are of actual need of implementation of probable measures of conservations so that the economic losses can also be reduced with good planning.

CONCLUSION

The hydrological modelling techniques are in use worldwide by many researchers to assessing the impacts of developing future. Hydrological models such as SWAT are used in the different disciplines for the potential impact assessment of water resources due to changing climates and land use conditions. From the studies above, it can be seen that SWAT model is in use for number of topics and has become acceptable and valuable tool for planning and managing conservation measures in the basin scale studies. Model can be used for the short term as well as long term impact assessment from small scale basins to large scale basins. SWAT can be used for forecasting the climate as well as topographical conditions for any catchment with reliable data availability or identical catchment data for the ungauged areas reducing the problems of data. Given the results showed by the reviews showed above, SWAT can be one of the best hydrological modelling tools used for natural resources management with argument throughout the world.

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