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Soil and Water Assessment Tool (SWAT) Modelling: A Review

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Abstract:- In the recent years human activities and climate change affected the hydrological cycle under the shifting environmental conditions worldwide and dispersed hydrological modelling based on practical methods have become the key topic for hydrological research. There are so many hydrological tools are developed to predict the future patterns by analyzing the historical data. Soil & Water Assessment Tool (SWAT) model is one of the distinctive distributed hydrological models which has been extensively used in hydrological research and to predict the future streamflow of rivers and sediment flow and agricultural production. This paper aims to analyze the research progress based on Soil & Water Assessment Tool in recent years. This paper focused on some prevailing glitches, sought the future research areas, and anticipated model enhancement to acclimate to the local environmental variations. This study should be beneficial to beginners in the field of SWAT modelling and also should be valuable for future development of SWAT models. It will also provide reference for users of SWAT modelling in related subject.

Keywords:- *Climate Change, Hydrological Modelling, Soil & Water Assessment Tool (SWAT).*

I. INTRODUCTION

Hydrological modelling has been used globally as a commanding tool for water resources research and management. Many researchers have focused on hydrological modelling of the areas that have experienced an enlarged frequency of extreme events i.e. drought and flood. Over recent decades, hydrological modelling has facilitated in the enhancement of the conservation and sustainable use of water resources as well as other natural resources, exclusively through researches on impacts of land use/land cover changes, mitigation of climate change and water pollution [1].

The hydrological modelling principally includes empirical models, conceptual models and physically based models. Due to the boosted impact of human activities and climate change on the environment, the underlying surface changes significantly, more extreme precipitation and temperature events happened, and conceptual models could not reflect the change of runoff and nutrients caused by the spatial difference of the underlying surface. But distributed models divide the whole watershed into small units with almost identical properties, the simulation results of which are closer to authenticity [2,3].

The essential responsibilities of water resources research under changing environment are to objectively evaluate the periodicity and randomness of the water cycle and quantitatively recognize the aids and modes of natural and artificial factors that drive the evolution of water cycle, reproduce the historical process of the water cycle to predict the future, and serve water resources regulation and control decision-making. The distributed hydrological model can quantitatively pronounce the process of hydrological elements and is an effective technical way to identify the evolution law of water cycle. It is of great significance for the rational development, utilization and management of water resources [4].

The Soil and Water Assessment Tool (SWAT) was established to forecast the variation in the quantity and quality of water, sediment yield, chemical and pollution level of water in different sources of water due to different types of water management practices across the globe. Due to its prediction efficiency this model has been used by all over the world for water management and various hydrological research applications. After the successful development of a SWAT model, it is calibrated with actual data and validated for future prediction. A number of methods are available for calibration and validation of the SWAT model. The Sequential Uncertainty Fitting-Version 2 (SUFI-2) algorithm is mostly used technique for the calibration and validation analysis of a SWAT model [5]. The established results of the SUFI-2 indicate the efficiency of SWAT model and integrated SWAT model helps in simulation of streamflow and sediment yield.

II. OBJECTIVE OF THE STUDY

The primary objectives of this study are: (1) to summarize the structure and principle of SWAT model, and (2) to analyse the existing problems in the development of SWAT model based on previous published literatures and the summary of the application status of SWAT model both at home and abroad in recent years.

The results of this study will help the beginners of hydrological modelling to thoroughly understand the SWAT model and its data inputs, structure and applications. It will also provide reference for further enhancement of the SWAT model.

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III. SWAT MODEL DESCRIPTION

SWAT model is developed by the USDA Agriculture Research Service (USDA-ARS), and it is a semi-distributed model of watershed scale and continuous time [6]. SWAT officially launched the original SWAT 94.2 version in the early 1990s, and has been constantly updated and upgraded till now. The latest version is SWAT 2012 (https://swat.tamu.edu/). The source code of SWAT model is available online for free. Functioning of SWAT model is based on daily time step. The main objective to develop SWAT was to predict the impact of various activities i.e. land use/ land cover change, climate change over the years on stream flow of gauged and ungauged watersheds and water quality parameters. SWAT simulation process entirely can be divided into two major parts the land surface which includes runoff and slope confluence and the water surface which contains concentration of channel. The SWAT input contains the meteorological data (Temperature, rainfall, windspeed etc.) and LULC map, slope map of the watershed. The SWAT model simulates infiltration, percolation, plant growth, runoff, and nutrient loads to enumerate the effects of climate change, land use and water management. The major advantage of SWAT model is that it proficient of constant simulation over a long period as much as 100 years. SWAT processes all the input data and determines the movement of water, sediment and other substances from the river network to the basin and the calculate the load [7,8].

In the SWAT modelling the bigger watersheds are further divided into small catchment areas which are known as sub basins and sub basins are further divided into smaller unit which have identical features are known as the Hydrologic Response Units (HRU's). Modified SCS curve number and Green-Ampt infiltration method are two methods which SWAT use for simulating the streamflow or surface runoff. Penman-Monteith method, Hargreaves method and Priestley-Taylor method are the three methods which are used by SWAT to calculate the potential evapotranspiration. Lateral flow is simulated by the kinematic storage model [10]. Shallow aquifer is used for simulation of the return flow. Water balance equation of SWAT model which directs the hydrological balance is expressed as:

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

Where:

- SW_t: Final water content of the soil
- SW_0: Initial water content of the soil on i^{th} day
- Q_{surf}: i^{th} day surface runoff
- R_{day}: Precipitation i^{th} day precipitation
- E_a: i^{th} day evapotranspiration
- W_{gw}: i^{th} day return flow
- W_{seep}: Seepage water on day i
- All the parameters are in mm

The SCS curve number is defined with the subsequent equation:

$$Q = \frac{(P - I_a)^2}{\left(P - I_a\right) + S}$$

Where:

- Q: Runoff depth in mm
- P: Effective precipitation mm)
- S: Maximum potential retention
- I_a: Initial abstraction of water in (mm)

I_a is the function of Maximum potential retention

Therefore,
$I_a = \lambda S$
Where:
λ=0.2. Therefore, I_a=0.2 S
Hence, by integrating both Eqs. we have;

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

The runoff occurs when the value of P is greater than 0.5 S. Maximum retention potential of S is accompanying to the unitless parameter SCS curve number (CN) using the following equation.

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

The SCS curve number (CN) is subjected with permeability of soil, land use, soil–water conditions and infiltration. The SCS curve number value can be described by the three conditions (wet, moist, and dry). The SWAT output develop and validate various parameters i.e., streamflow, surface runoff, evapotranspiration, reservoir water balance, deep aquifer, interception storage and infiltration [11].

The model simulation results are generally evaluated using the regression correlation coefficient (R^2), Nash-Sutcliffe modelling efficiency (NSE). Generally, if R^2 >0.6, NSE>0.5, the simulation accuracy of the model meets the requirements, that is, the SWAT model is suitable to simulate the watershed [12].

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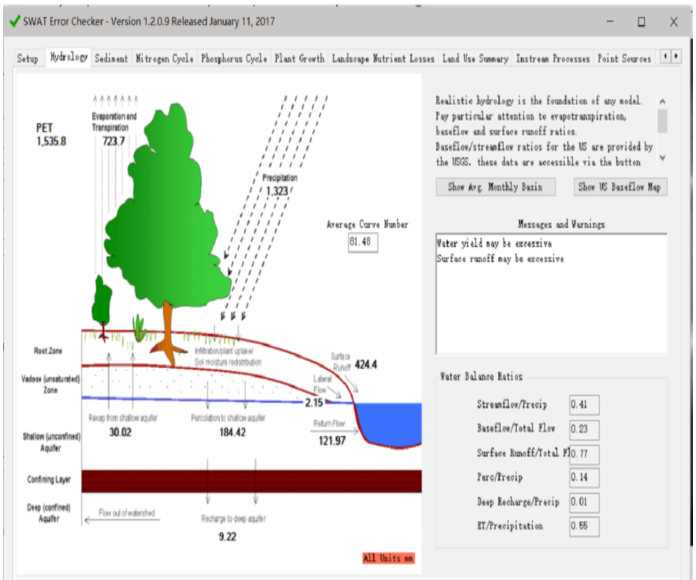

Figure 1. The hydrological cycle process of SWAT model.

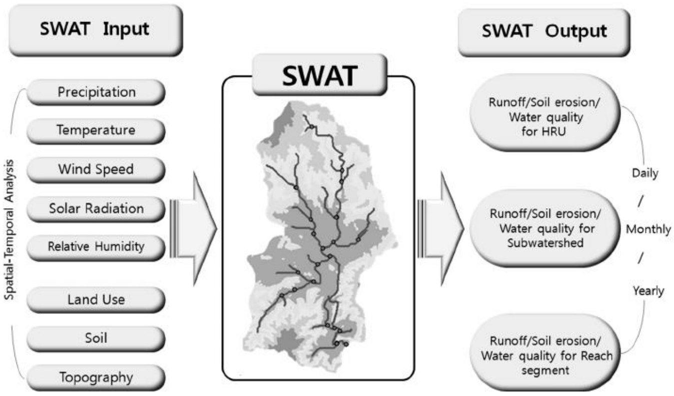

Figure 2: SWAT Model Input and Output

IV. RUNOFF SIMULATION

Runoff is the product of the combination of various natural and geographical factors such as climate and underlying surface in the basin. Runoff simulation is a significant part of hydrological simulation research and the basis for studying other hydrological problems [13]. The runoff simulation is mainly divided into two stages. The first part is to determine the parameters in the model based on historical data of a certain length, and the second one is to use the model to simulate the runoff of the verification period or predict the future runoff. The runoff simulation is mainly composed of surface runoff, evapotranspiration, soil water and groundwater [14]. The methods for calculating surface runoff are Soil Conservation Service Curve Number (SCS-CN) method and Green-Ampt infiltration method. Generally, the former is used more frequently. In the literature related to runoff simulation scholars applied SWAT to runoff simulation which are no longer just the simple application of the model in recent years. Foreign scholars are more concentrated on studies of influencing factors of simulation accuracy [15].

V. IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

"Hydrological cycle research under changing environment (i.e. global climate change and human activity influence)" is the core scientific issue of Global Water Systems Programme (GWSP). Land Use and Land Cover (LULC) Change is an important manifestation of "changing environment" [16]. The combination of water cycle and the terrestrial carbon cycle is a new cross-direction. The scenario analysis research methods of LULC hydrological impacts usually include reference comparison method, historical inversion method, model prediction method, extreme land use method, and land use spatial allocation method. At present, many scholars have applied the SWAT model in different watersheds to analyse the impact of climate change and confirmed the adaptability and credibility of SWAT model [17].

VI. DISCUSSION

SWAT is widely used in many aspects of water cycle simulation, but it still has certain limitations. For the current era of big data, there are still some problems and improvements in the application of SWAT.

- Time scale problem

In the application process of SWAT model, most scholars used the year, season or month as the time scale for simulation and analysis, and rarely took day as the time step to simulate. The result is mostly consistent with that of previous study that SWAT can effectively simulate the hydrological process of long time series, but the simulation accuracy decreased with the shortening of time step, especially the simulation of daily runoff has systematic errors [18].

- Uncertainty analysis issues

SWAT was proposed by American scholars. The data used in the model, such as land use types and soil types, are all based on the localization of the United States. Chinese scholars need to establish attribute database according to the land use types and soil characteristics in the study area when applying the model, which is the main reason for the low simulation accuracy of the model for the research area with incomplete data. And the input of parameters also has some uncertainty on the simulation accuracy. At present, many scholars have done a lot of research on sensitivity analysis and uncertainty analysis of parameters [19].

- Model updating problem

Under changing environment, the relationship between rainfall and runoff is non-stationary, and real-time dynamic runoff simulation is required. The current SWAT model needs to use the latest data for calibration to make the prediction result more accurate when new data are added, which forms a mechanism of constraint and feedback between the latest data and future prediction data. But this method is time consuming and laborious. In the future research, an algorithm can be added on the basis of the SWAT model source code, so that the calibration process becomes a self-learning process of the model, and the model opens the self-learning mode while the latest data enters the database, which can be self-calibrated for more accurate simulation [20].

VII. CONCLUSIONS

The wide application of SWAT model at both domestic and abroad has confirmed that it is a powerful and comprehensive hydrological modelling tool. At present, domestic and foreign studies on this model mainly focus on model application, model accuracy and model coupling. The application field of the model are still mainly runoff simulation, climate change and water pollution. But the research content is no longer the simple application of the model. The main research contents of runoff simulation are the study on model accuracy, such as the influence of DEM resolution and other factors on the simulation accuracy, and the adaptability of the model in special areas. In order to adapt to the changing environment, SWAT model still has many directions for improvement, so as to better simulate the water cycle, serve water resources scheduling decisions, and provide support for water resources management.

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