iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** I **Month of publication:** January 2020

DOI: http://doi.org/10.22214/ijraset.2020.1030

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 8 Issue I, Jan 2020- Available at www.ijraset.com

Hydrological Modeling with Soil and Water Assessment Tool (SWAT): An Overview

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Abstract: Hydrological modelling is becoming a vital and indispensable tool for water research and water resources management. Hydrological models helps to understand the present and past water resources in a watershed and also helps in exploring the consequences of certain management decisions and related imposed changes. Furthermore, hydrological modeling is also supported for effective management of water resources in order to inform the decision makers related to national development and secondly to reduce the trans-boundaries conflicts by encouraging equitable allocation. The Soil and Water Assessment Tool (SWAT) is one of the most recent semi-distributed hydrological model established by USDA. It is a versatile physically-based watershed model used across the world for hydrological concerns and to evaluate quality of water under varying environmental conditions.
This paper presents the types, purpose, structure and complexity of different hydrological model. Also, an overview of the SWAT model, its capabilities, development and hydrological components are discussed in details.
Keywords: Hydrological modeling, Geographic Information System, Soil and Water Assessment Tool (SWAT)

I. INTRODUCTION

Hydrological modeling is the "The interactions between several hydrological processes which differ both in space and time, such as rainfall, streamflow, evaporation, infiltration and the quantitative representation of such interactions through observation, analysis and prediction [1]. Modeling provides us a clear depiction of the processes to be used for forecasting probable effects of present/future scenarios, therefore, providing solutions to real-world problems with such details that are almost unachievable with conventional analysis.
Moreover, modeling is essential in hydrology because it is almost unrealistic and difficult to establish physically the hydrologic interactions at some representative points in the catchment.
In addition, any changes in the system, as a result of human activities, need to be addressed earlier to facilitate mitigation actions on proper time. Thus, modeling is the individual possible mean to examine the future and to determine what will be the situation if existing circumstances improve, stay constant, or get worsen.

II. GENERAL CLASSIFICATION OF MODELS

Models may be classified as below [2] [3].

A. Purpose of the Model

The type of model to be used mainly depend upon the purpose/objective of the modeling application. For instance, modeling short period events such as floods, single event models are preferable. However, models with continuous simulation are more appropriate to simulate events of longer period and frequent occurrence. Such models that link hydrology, abstraction and return flows and the storage effects, are mainly preferred for water resource management.

B. Model Structure

Modeling is adopted to predict the outputs response upon the study of the available inputs of the climate into the hydrological processes i-e model using the input data helps in predicting the response of output where the outputs include soil moisture, groundwater and streamflow. Therefore, the model complexity is determined through the extent of this definition. A detailed representation cannot be achieved by simple models using few sets of parameters. Although more complex models required larger number of parameters, hence, all the input and output processes are defined clearly.

C. Spatial Complexity

In general, two techniques of modeling are used, in first technique, the area as a whole is considered homogenous and likewise, for the whole area a single flow process is established.

On the flip side, the other technique is based on dividing the area into segments or various sub-lands based on either their geometry or drainage. Within the area, the flow processes are defined at individual point. The quality of data available for specific areas is the governing condition for selection of a particular method to use.

D. Temporal Complexity

For a hydrological process, the time step of each model is used to describe their temporal complexity whereas these time steps vary from model to model, in some from minutes to years while in others they vary inside the model run in ways they capture special events such as flood or extreme rainfall.

III. TYPES OF HYDROLOGICAL MODELS

Different types of hydrological models are much difficult to distinguish because each model is a group of modules, computing certain components of the hydrological process and each of these modules may be related to a specific kind of model which depends on the kind of objective which it had set for the model and also the quality of data available [4].

A summary and description of every type of the model gathered from [5], [6], [7], [4] [8] and [9] are presented here.

1) *Deductive Models:* Deductive models formulate a precise conclusion depending on common facts and known details that govern physical laws, which are understood well.
2) *Inductive Models:* The inductive models use a series of facts for deriving a certain conclusion. There is observed correlation among the fact and conclusion however the exact mechanism might not be understood. The discovery of patterns from observed data may have resulted from this logical approach. The following kinds of models develop depending upon the logical approach used.
3) *Stochastic Models:* These models introduce the probability concept due to the fact that they are based on the probability of existence input data and/or the model parameters itself. Hence, the output will also vary accordingly [9].
4) *Deterministic Models:* Based on physical laws, deterministic models explain the catchment processes in the form of mathematical relations and not on chances of occurrence. Furthermore, these models are based on initial and boundary conditions and are further divided as the following;

a) *Empirical Models:* Also called as 'black box' models. Such models do not consider the physical processes in the catchment and are driven by correlation and regression equations result from statistical studies of observed time series data.

b) *Process-driven Models:* To define a processes, these models are based on mathematical relationships and are deductive in nature. Also called as 'white box' models and can be further distributed into conceptual models, which primarily related to the natural phenomena instead of the physical processes, and physical models, which are based on complete depiction of catchment processes and need reasonable input data.

Models having physical as well as empirical components are termed as semi-empirical or 'grey box' models.

Considering the catchment characteristics, a further division of the above can be described as;

i) *Lumped Models:* The Lumped model considers the catchment as a homogenous element and ignores the spatial variations in parameters and further does not represent the physical features of a watershed.

ii) *Distributed Models***:** A distributed physical-based model mostly requires a large amount of data for parameterization [10]. These models instead provide a detailed description of catchment processes. These models have highest degree of accuracy and based on catchment characteristics, it breaks down the whole catchment into different HRUs.

iii) *Semi-distributed Models:* Such models are a combination of the lumped and distributed models. In these models, semi-empirical equations are used for the descriptions of the hydrologic processes. In sub-catchments or in HRUs level, some sort of distribution is implied and further, the areas with the identical features are combined to sub-units.

IV. GIS-BASED HYDROLOGICAL MODELING

The increased availability of the spatial datasets and improvement in computer technology has enhanced the capabilities to precisely define characteristics of the watershed during the estimation of runoff response from precipitation. The conventional ways have been efficiently replaced by GIS and Remote Sensing techniques and further support the efforts acquired for sustainable water resources management & development. Furthermore, the model capabilities enhanced by incorporating the spatial heterogeneity in various complex hydrological processes during hydrological modeling [11]. Hydrological models are extensively used for water resources management in a sustainable way. For achieving better hydrological modeling outcomes, models are usually coupled with GIS to simulate various hydrological parameters [12]. In hydrological modeling, GIS incorporates the diverse spatial/non-spatial data which can be model as input or output. In addition to Remote Sensing, GIS has significantly contributed to evaluating and managing spatial data and hence serves as a suitable tool for hydrological analysis [13]. The GIS combination with hydrological models has increased and boost up the usage of remotely sensed data in hydrological applications. Modeling hydrology with GIS also provides more realistic approach towards the watershed conditions, defining watershed characteristics, enhancing efficiency of the modeling procedure and ultimately increased the estimation abilities of hydrological modeling [11]. GIS is also very effective in displaying data spatially than temporally. GIS has become an important tool for the and particularly for hydrologists in the scientific studies related to water resources and sustainable ecosystem. Climate change studies and its effects requires very comprehensive knowledge and information because of spatial and temporal variability throughout the process. With the development of geospatial technology, it is becoming progressively dynamic and associating the gaps between historical data management and hydrologic realities [14]

V. INTRODUCTION TO SOIL & WATER ASSESSMENT TOOL (SWAT)

A. SWAT Model

The SWAT is one of the most recent semi-distributed hydrological model which is established by USDA, Agricultural Research Services in 1970. It is a versatile physically-based watershed model and used across the world to evaluate quality of water and hydrological concerns under varying environmental conditions [15]. The model uses a command structure for routing runoff and chemical [10] and is capable to simulate eight key mechanisms; such as hydrology, weather, plant growth, nutrients, sedimentation, soil temperature, pesticide and land management through the basin [16]. The main purpose of SWAT is to interpret the physical functioning of the above different components and their interactions more realistically as possible with the help of available input data and through conceptual equations, which can be helpful in decision making process of large catchments management and in routine planning [17].

B. SWAT Model Development

The SWAT model was originally developed in GRASS with Arc View interface under HUMUS project. This was a very large-scale project of USA in which the manual approaches for the assembling of these large scale datasets for SWAT model simulation were workable. So, GIS interface was developed to prepare and manage these datasets and process maps for large -scale modeling. With the development in the technology, the SWAT model also completed various stages of its development and finally is compressive in its approach to model the hydrological and agricultural parameters with Arc GIS interface. With Arc GIS interface, it delivers skills to re-structure many GIS methods and support to mechanize in data entry; editing and effective communication among GIS datasets and the SWAT model. Similarly, Arc SWAT also allows simplicity in pre and post handling of spatial input datasets.

C. Model Capabilities

SWAT Model was actually designed with the idea to forecast the effects of agricultural management decisions on water quantity and most important the water quality for small, medium and large basins. It turns on a daily and sub-daily time set for short or long term predictions whereas monthly and yearly basis outputs could also be generated. As, SWAT model is mostly used to analyse the effects of land management practices on water resources [18].

The hydrological responses to land use and climatic changes are mostly reviewed through scenario-based simulations with the help of SWAT model [19]. Due to computational efficiency, large basins simulation or different types of management strategies can be easily performed through SWAT.

It also helps researchers to examine the long-term effects [20]. According to Anwar, N. (2010), SWAT model has obtained international acceptance as a strong multidisciplinary physical based hydrological modeling tool. In case of data scarcity, SWAT can model the watershed with free availability of GIS data and is one of the main advantages of SWAT [21].

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D. Hydrologic Components of SWAT

In SWAT, the division into sub-basins are essential to replicate the variations in Evapo-transpiration for different soils and crops. In the same way, for each sub-basin, the runoff can be calculated separately and further transmitted to calculate the overall runoff for the whole catchment, which will provide precise and true depiction of water cycle [22]. The method employed in SWAT for calculating surface runoff is either Curve Number (SCS-CN) method or Green Ampt infiltration method [23, 24]. The SCS-CN is primarily depends on the soil properties, hydrologic conditions and LULC extensively used for the estimation of indefinite quantity of overflow from a specified rainfall event. The CN varies from 30 to 100 and the lower number shows the low runoff while, the large CN value indicates the increasing runoff.

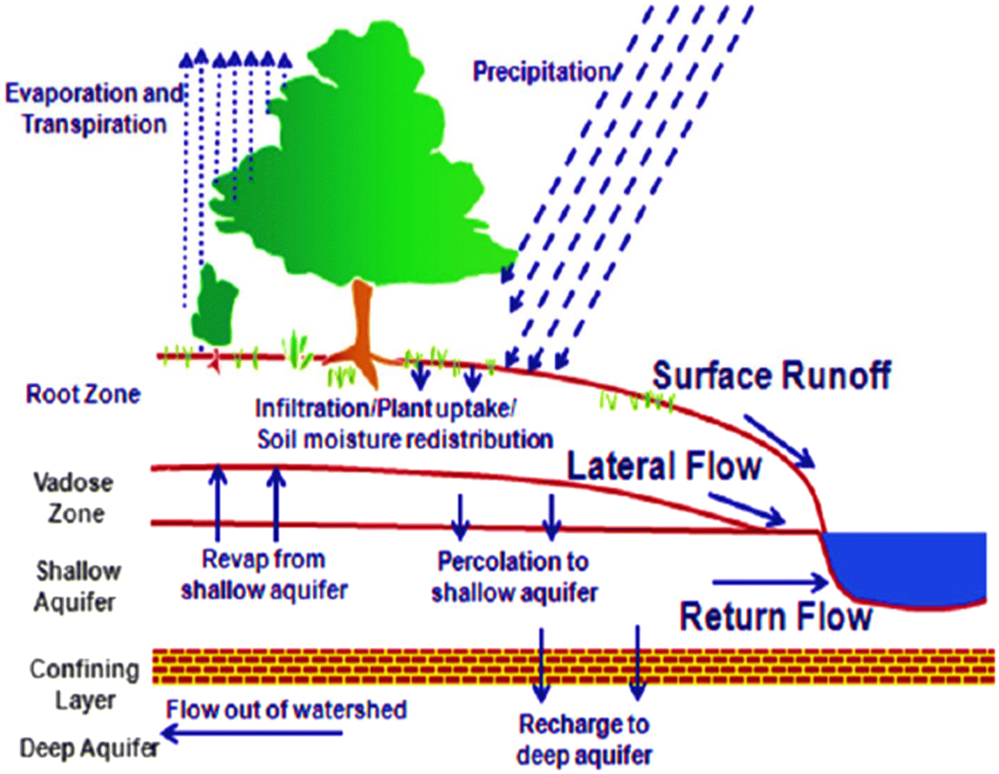

Figure 1: Visual representation of the soil water balance equation used by SWAT model

Furthermore, potential evaporation can be calculated by any one of the three methods namely; Hargreaves, Priestly-Taylor and Penman-Monteith [10]. Out of the three potential-evaporation calculation methods, the appropriate one could be selected based on the climatic condition.

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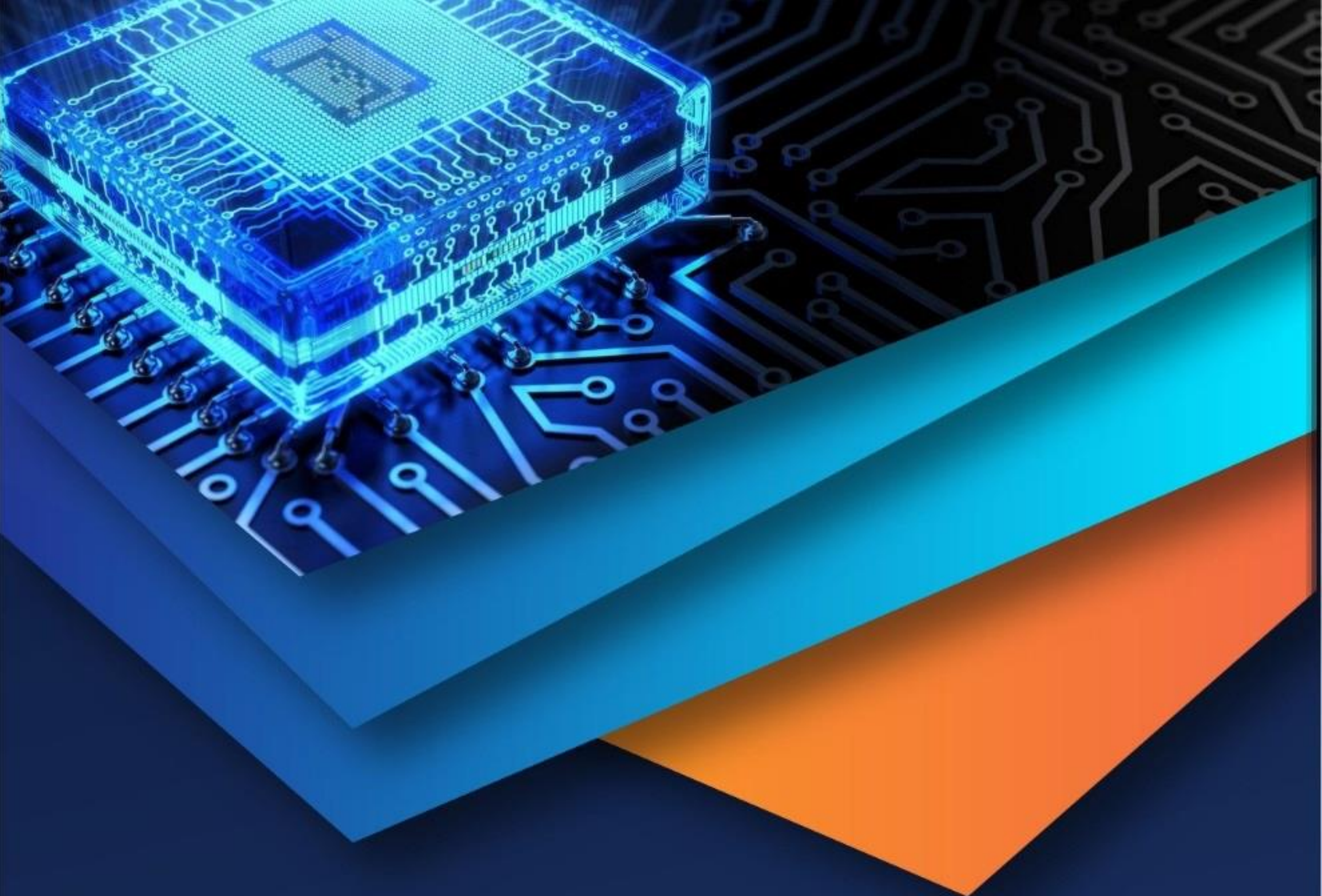

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