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A SEMI-DISTRIBUTED HYDROLOGICAL MODEL IN HUMID TROPICAL CLIMATE USING MALAYSIA SOIL DATA

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ABSTRACT

The idea of watershed modeling is implanted in the interrelationships of geospatial and hydro-meteorological data and represented through mathematical abstractions. The behaviour of each process is controlled by its attributes as well as by its interaction with other processes active in the catchment. In recent years, distributed watershed models have been increasingly used to implement alternative management strategies in the areas of water resources study. Many of these models share a common base in their endeavour to incorporate the heterogeneity of the watershed and the spatial distribution of topography, vegetation, land use, soil characteristics and rainfall. For soil maps, all the physical properties were used as input files for SWAT models. The study attempts to assess the whole simulation processes of the SWAT hydrological model using a Malaysia soil data. It was found that the SWAT model can be successfully applied for hydrological evaluation of the Langat River Basin with the coefficient of determination, R2 value of 0.7529. Finally, the paper concludes by identifying key issues and gives some directions for future research.

KEYWORDS: Malaysia soil data, SWAT model, Langat River Basin, coefficient of determination.

INTRODUCTION

Hydrology is a subject of great importance to human and the environment, which deals with all phases of the earth's water [1]. The discipline has many practical uses such as in the design and operation of the hydraulic structures, water supply, wastewater, irrigation, flood control, erosion and sediment control, pollution abatement, recreational and many mores application [2] & [3]. In Malaysia, the Info Works Collection System (CS) and Stormwater Management Model (SWMM) are among the most broadly utilized programming to model drainage systems [4]. However, many more hydrological models were found in the literature have been utilized for the watershed modeling study in the nation. These included a Hydrologic Engineering Centre-The Hydrologic Modeling System (HEC-HMS) software [5], [6] & [7]; followed was the MIKE SHE models [8] and finally the most current model is the Soil Water Assessment Tools (SWAT) software [9], [10]. Among these models, the physically based distributed model SWAT is well established for analyzing the impacts of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds [11].

In distributed hydrological study, a spatial heterogeneity of the watershed is represented by the differences in the topography, land used and soils maps. The attribute data of the digitized maps will describe detail properties of the related maps. For soil maps, all the physical properties were used as the input files in SWAT models. Soil characteristics control hydrologic processes such as rainfall infiltration, percolation, and moisture storage. Some soil properties, e.g., saturated hydraulic conductivity will react as a control entry of precipitation inputs into the soil, and consequently the generation of infiltration-excess runoff. Other soil properties control soil moisture storage. These latter soil descriptors include soil depth, porosity, plant-available water content and depth to bedrock or the water table. Soils normally retain water by capillary forces and release water through gravity, evaporation from the soil surface and transpiration from plant stomata.

SWAT, which is a public domain model, has been successfully used by researchers around the world for distributed hydrologic modeling and management of water resources in watersheds with various climates and terrain characteristics. The model provides the continuous-time simulation to facilitate the real watershed responses in long simulation periods. SWAT model using the USDA database when dealing with the soil data. In common practice, there are two options of the modellers utilized soil data in the model, either straight away using the default USDA soil series which is comparable with local soil series or to include a new local soil data in the model input file. The second option is more preferable to be practiced due to the accuracy of the results and genuine to describe the soil property in the watershed. The study attempts to highlight the whole simulation processes of the SWAT model using a Malaysia soil data. The first section gives some basic explanation of the classification and properties of Malaysian soil data. This is important for the researcher to embed the soil properties in the range of hydrological modeling. The second section discussed the details soil input parameter available in SWAT model and its relation to the existing of Malaysian soil series. The third section explained on the method and materials being utilized in the study area, the upper part of Langat River Basin and followed by the SWAT model input and setup. Then, the fourth section discusses on the SWAT simulation output of the basin. Finally, the paper concludes by identifying key issues and gives some directions for future research.

DEVELOPMENT OF MALAYSIA SOIL DATA

The progress of soil science in Malaysia has mainly been spearheaded by soil surveys, and other branches of soil science have mainly played an invigorating role. Soil surveys in each of the three regions of Malaysia initially developed separately and to a large extent remain separate. The development of soil surveys in Malaysia can be divided into three main periods [12]. The pre-independence period from around 1882 to 1955 saw mainly ad hoc soil surveys by British staff of the Department of Agriculture. The second period, which lasted from around 1955 to 1990, saw systematic reconnaissance soil surveys being carried out mainly to locate areas with potential for agricultural development. The third period from 1990 saw the advancement of a Malaysian Soil Taxonomy by modifying soil taxonomy to suit local conditions. The soils are generally studied with close reference to the parent material. Soil parent materials range from various forms of alluvium, sandstones, and mudstones to basic and ultrabasic igneous rocks, giving rise to a wide spectrum of soil types.

A basic unit of soil mapping in Malaysia is a soil series. The system is based from the USDA Soil Taxonomy, 1992 and to date; more than 240 soil series had been established and rearranged to eleven groups [13]. These groups are based on a parent material, characteristics of the dominant soils, landscape and methods of soil formation. Soils are classified into two main categories; mineral soils and organic soils. Soils under mineral soils group then been classified based on the soil taxonomy, but the criteria and definition were modified to suit the local conditions. While the sub-classifications of the organic soils are work out based on a level of organic matters and its depth using modified criteria of soil taxonomy.

The soil properties are strongly affected by three forces, such as hydraulic conductivity, diffusivity, and water holding capacity. The hydraulic conductivity is of critical importance to the infiltration rate since it expresses how easily water flows through soil and is a measure of the soil's resistance to flow. A saturated hydraulic conductivity is referring to the hydraulic conductivity at full saturation. Many of the infiltration equations in the hydrological models were using the saturated hydraulic conductivity as a parameter since it is easier to determine compared to the unsaturated hydraulic conductivity or the diffusivity. Diffusivity is the proportion of the hydraulic conductivity to the differential water capacity or the flux of water per unit gradient of water content in the absence of other force fields. Since the diffusivity is directly proportional to hydraulic conductivity, usually only the saturated hydraulic conductivity is applied in the approximate infiltration equations.

Water holding capacity is the amount of water can hold due to the pore size distribution, texture, structure, the percentage of organic matter, chemical composition and current water content. For saturated condition, the water holding capacity is zero, and the hydraulic head is positive. The soil texture that consists of the proportion of sand, silt, and clay give directly affects the hydraulic conductivity, diffusivity and water holding capacity. Soils with higher sand percentages, for example, have larger size particle, larger pores, lower water holding capacity and higher hydraulic conductivity, diffusivity and infiltration rates than clay soils which have smaller micropores and bind water molecules more tightly.

Antecedent or initial water content affects the moisture gradient of the soil at the wetting front, the available pore space to store water and the hydraulic conductivity of the soil. Initial water content is, therefore, a critical factor in determining the rate of infiltration and the rate at which the wetting front proceeds through the soil profile. The drier the soil initially, the steeper the hydraulic gradient and the greater the available storage capacity and increase the infiltration rate. The wetting front proceeds more slowly in drier soils, because the greater storage capacity, which fills as the wetting front proceeds.

SWAT SOIL INPUT PARAMETER

There are about 26 input data in SWAT model. These include input of groundwater, soil, main channel, management, management option, HRU, sub-basin, basin, initial pesticide, SWQ, pond, crop, fertilizer, water quality, reservoir, operational, pesticide data, septic system, tillage, urban, weather generator, snow, water removal, precipitation and temperature. Table 1 shows all the 15 soil input parameters provided in the SWAT input table with 12 required parameters to allow the simulation processes. There are three main references of the soil input properties of existing Malaysian soil series. The first reference is compiled all the major soil mapping units of Malaysian soil. About 100 soil series mapped in Peninsular Malaysia is details elaborated in terms of soil characteristics and its identification [14]. The manuscript explained more details of the range of characteristics of every soil series, the distribution and extent and also the suitability for agriculture. The organic carbon contents and soil texture of clay, silt, fine and coarse sand were quantified in details.

The second manuscript is a simplified version of the major soil series in Peninsular Malaysia. The compendium explained the details soil information to be used as a basis of the soil management and agronomic practices. Soil information from the eleven different groups was explained by its soil classification, distribution in Peninsular Malaysia and the soil suitability for agricultural purposes [13].

The last reference is providing the guidelines for erosion and sediment control in Malaysia and was prepared by the Department and Irrigation (DID), Malaysia [15]. Soil erodibility defines the resistance of the soil to both detachment and transport. It is an important index to measure soil susceptibility to water erosion, and an essential parameter needed for soil erosion prediction. The soil erodibility factor (K) represents the effect of soil properties and soil profile characteristics such as soil texture, aggregate stability, shear strength, infiltration capacity, organic and chemical content on soil loss. There are many attempts have been made to devise a simple index of erodibility based either on the properties of the soil as determined in the laboratory or the field, or in the response of the soil to rainfall. Of these studies, the Malaysian DID department was adopting the Tew Equation and Nomograph [15 &16]. The method has been found to give the most satisfactory estimation of K factor for Malaysia soil series, and, therefore, recommended for the calculation of K factor in this guideline. Under the manuscript, about 74 value of USLE equation soil erodibility (K) factor was provided for major soil series in Malaysia.

Table 1. SWAT Soil Input Parameter

No	Soil Input Parameter
1.	Maximum rooting depth of soil profile.
2.	The fraction of porosity from which anions are excluded.
3.	Crack volume potential of the soil.
4.	Texture of soil layer.
5.	Depth from the soil surface to bottom of the layer.
6.	Moist bulk density.
7.	Available water capacity of the soil layer.
8.	Saturated hydraulic conductivity.
9.	Organic carbon content.
10.	Clay content.
11.	Silt content.
12.	Sand content.
13.	Rock fragment content.
14.	Moist soil albedo.
15.	USLE equation soil erodibility (K) factor.

There are three others major soil physical input parameters that were needed by the SWAT model that are not provided in the above references. These include a moist bulk density (SOL-BD), available water capacity of the soil layer (SOL_AWC) and saturated hydraulic conductivity (Ksat). The soil sampling and laboratory testing are needed in providing these data to gain the most reliable simulation of SWAT watershed model.

SWAT MODEL SETUP

The spatially distributed data in GIS input is required for the ArcSWAT interface include the Digital Elevation Model (DEM), soil data, land use and stream network layers. Data on the weather and observed streamflow were also used for prediction of streamflow and calibration purposes. DEM was derived mainly from a contour map of 20m interval and a digital river network, which were provided by Department of Survey and Mapping Malaysia (JUPEM).

The mainstream of the Langat River which stretches for 141km has a total catchment area of 2271km2 and lies within latitudes of 2º40'152"N to 3º 16'15"N and longitudes of 101º19'20"E to 102º1'10"E. The main tributary, Langat River flows from the main range (Titiwangsa Range) at the Northeast of Hulu Langat District in south-southwest direction and draining into the Straits of Malacca as in Figure 1. Topographically, this basin can be divided into three geographic regions, i.e. the mountainous area of the north, the undulating land in the centre of the basin and the flat flood plain at the downstream of Langat River.

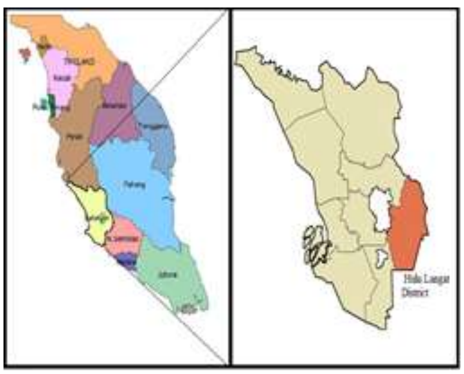

Figure 1. Location of Langat River Basin.

The land used map of a study area was obtained from Department of Agriculture, Malaysia. The land use map needs to be reclassified according to the specific land cover types such as the kind of crop, pasture and forest. The dominant land used in the study area is a primary forest reserve (64.80%), followed by rubber (18.04%), urban area (7.58%), and orchard agriculture (3.69%). The majority of the study area is covered by a steepland (64.8%) and followed by a Renggam-Jerangau soil series (23.20%), Telemong-Akob-Local Alluvium (8.00%) and Munchong-Seremban (3.24%).

SWAT requires daily meteorological data that can either be read from a measured data set or be generated by a weather generator model. The weather variables used in this study are daily precipitation, minimum, and maximum air temperature for the period 1976-2010. These data were obtained from the Department of Irrigation and Drainage (DID) and Department of Environmental (DOE) Malaysia for stations located within the watershed. Daily river discharge values for the Kajang streamflow station Department of Irrigation and Drainage (DID) Malaysia. The insertion of Malaysia soil series in the SWAT input table of the study is prepared in the SWAT.2009mdb database input file as shown in Figure 2. The sub-basin discretization processes only focused on the 305.3km^2 upper part of the Langat River Basin.

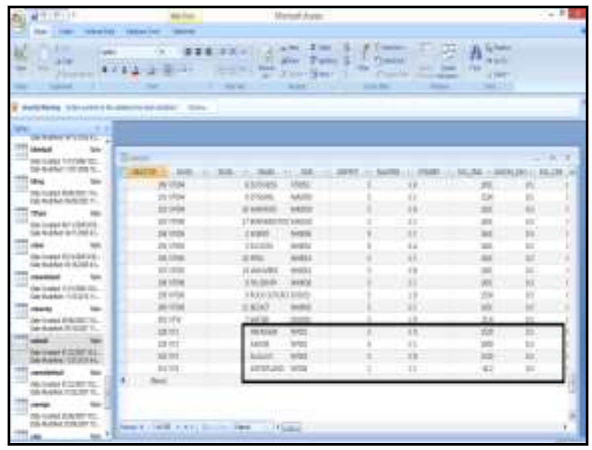

Figure 2. Malaysia soil series in the SWAT.2009mdb database input file.

SWAT SIMULATION OUTPUT

The comparison of default simulation output with the observed streamflow data of Kajang streamflow station showed an agreement between the observed and simulated flow results. Parameters manually adjusted were evaporation compensation factor (ESCO), curve number (CN2), available water holding capacity of the soil layer (Sol_AWC, mm/mm), saturated hydraulic conductivity (Sol_K, mm/hr) and surface runoff lag time. The manual calibration was time intensive, but it helped to get better automatic calibration results.

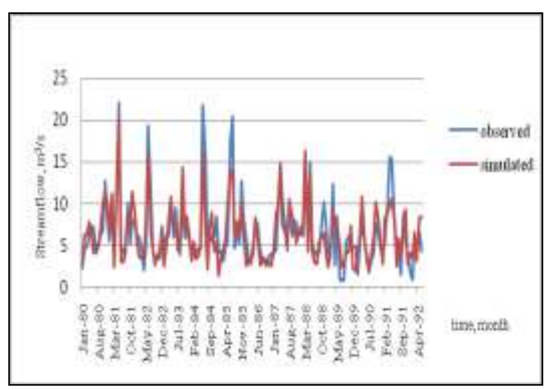

Figure 3. SWAT 13 years streamflow simulation output.

A graph of monthly streamflow hydrograph optimization output in Figure 3 shows the agreement between observed and simulated streamflow. A value of the coefficient of determination, R^2 of 0.75 as in Figure 4 was gained from a simulation, and the value can be considered as the proper achievement of the calibration processes in a hydrological model. However, it is also shown by the hydrograph that the model does not effectively simulate the monthly peaks discharge of the streamflow station. It is clearly observed that the simulated output in June 1984; July 1985 and May 1991 were lesser than the observed streamflow.

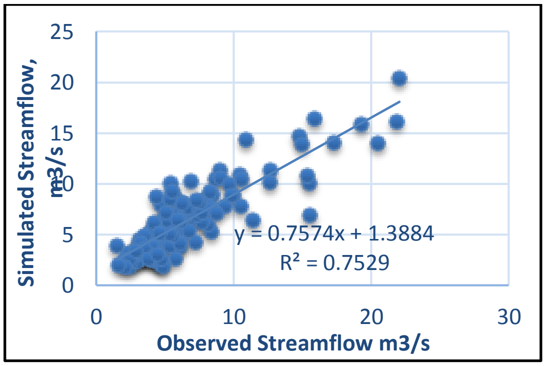

Figure 4. Coefficient of determination, R^2.

CONCLUSION

A watershed of the Langat River Basin was successful been modeled by the SWAT2009 model using a Malaysia soil series. The further process of calibration, validation, and the uncertainty analysis are needed to be conducted to gain an excellent SWAT model of the river basin. The sensitivity analysis of all the soil input parameters are recommended to be further explored consecutively in assessing the dominant factors in continuous simulation hydrological model.

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