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Assessment of hydrological processes in a small watershed using SWAT

V. Tejaswini and K. K. Sathian

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See end of the Paper for authors' affiliation

Correspondence to :

V. Tejaswini
Department of Land and Water Resources Conservation Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur, **Malappuram (Kerala) India**
Email : vallutejaswini@gmail.com

■ **ABSTRACT :** Water availability is declining and the demand is increasing, leaving the gap between these two more wide day by day. Quantifying the elements of hydrologic processes at micro watershed scale and at weekly or monthly temporal scale is the prerequisite for water resources development of a locality. Hydrologic modeling is a very powerful technique in planning water resources of a locality. Valancheri watershed, which is a sub basin of Bharathapuzha river basin, Kerala is taken for the study. As the study watershed is ungauged one, calibration was done for Kunthipuzha basin which is having similar characteristics with the study area and the calibrated parameters were transferred to the study watershed (Regionalization technique). The model was calibrated for the period 2000-2006 and validated for 2007-2009. Performance of the model was satisfactory with NSE = 0.81, R^2 = 0.82 for calibration period and R^2 = 0.95, NSE = 0.82 for validation period. The calibrated model was used to predict the hydrologic elements of the Valancheri watershed at micro watershed level. The simulation results were great use in planning water resources development of the locality.

■ **KEY WORDS :** Watershed model, SWAT, ArcGIS, Hydrological response units, Water balance components

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Water is the most indispensable natural resources for the survival of all living beings, but unfortunately this resource is becoming scarce day by day. Hence, scientific water management is a must to sustain the domestic and irrigation water needs. Conservation of water at micro watershed scale is prerequisite since all the hydrologic process takes place within individual micro watersheds. Physically based distributed watershed models play an important role in exploring a variety of watershed problems and to manage water resources. Currently, the use of distributed models has been increased in hydrologic applications (Pechlivanidis *et al.*, 2011). Some of the physically based models developed and presently in use are TOPMODEL (Beven and Kirkby, 1979), SHE, MIKE SHE, WEPP (Laflen *et al.*, 1991) and SWAT (Arnold *et al.*, 1998). SWAT is one of the physically based distributed watershed model which is widely used and highly recommended by the researchers (Arnold and Fohrer, 2005 and Gassman *et al.*, 2007). SWAT model was found to be computationally efficient in simulating the hydrology and water quality of the catchments in continuous time periods (Neitsch *et al.*, 2005 and Arnold *et al.*, 2012). SWAT model had got excellent capabilities in simulating surface runoff on monthly basis from small watersheds (Spruill *et al*., 2001). Saleh and Du (2004) compared the simulated values of SWAT and HSPF with the observed values of average daily flow, sediment loads, nutrient loads and found that the values simulated by the SWAT are closer to the observed values than HSPF. But calibration is not possible for the ungauged watersheds which makes physically based distributed watershed models outside the purview of ungauged basins. And also, at the same time, many watersheds in the world are ungauged watersheds and we cannot omit the unguaged watersheds since they are the only resource in many areas. Regionalized parameter sets obtained from the SWAT model can be used for making satisfactory hydrologic response predictions in ungauged watersheds (Gitau and Chaubey, 2010). Emam *et al*. (2016) also used SWAT to model hydrologic process in an ungauged basin of Central Vietnam by applying regionalization approach and succeeded in implementing the BMP's for the agricultural lands located in the ungauged basin. Against this background, a study was conducted on ungauged Valancheri watershed which is the major water source for drinking and agricultural activities in that area.

METHODOLOGY

The present study was conducted on Valancheri watershed near Kuttipuram in Kerala, India. The location of the study area was shown in Fig. A.

Softwares and tools used for the study:

Different softwares and tools were used for conducting the study which are explained below:

ARCGIS 10.22:

ArcGIS 10.22 which was released in 2014 was used in this study. ArcGIS 10.22 was used for changing the

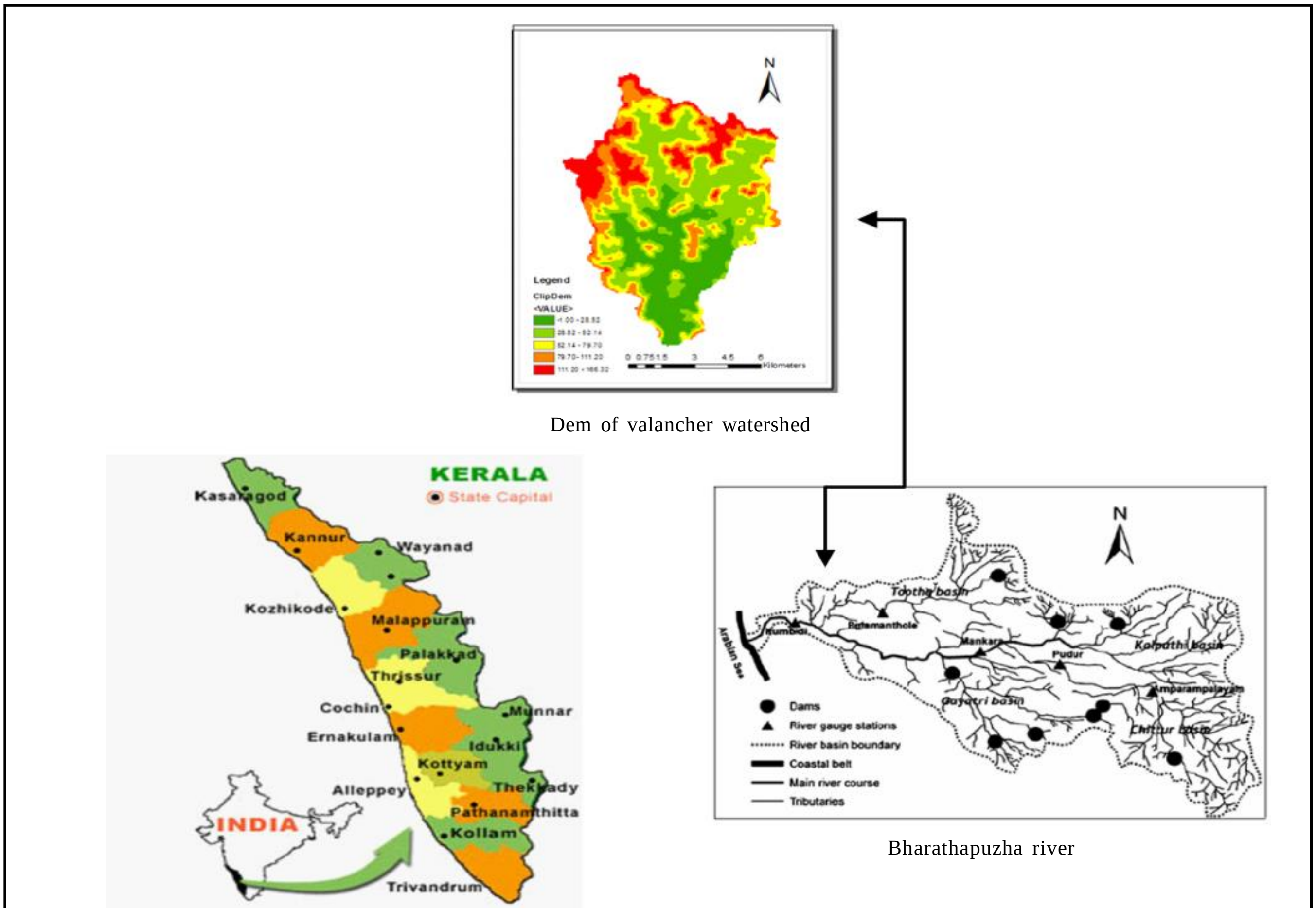

Fig. A : Location map of study area

projection of SWAT inputs such as DEM, land use and soil maps. Georeferencing the toposheet of the study area, digitization and the preparation of digital elevation model was also done using this software.

Soil plant atmosphere water hydrologic budget model:

SPAW model is used for calculating the characteristics of the soil. The soil characteristics required for the model such as hydraulic conductivity, electrical conductivity and bulk density were obtained from this software.

SWAT model:

SWAT is a physically based distributed watershed model that can operates on different time steps. It is a comprehensive tool that enables the impacts of land management practices on water, sediment and agricultural chemical yields for the watersheds with varying soils, land use and management practices. SWAT can also simulate sediment yield, transport of nutrients and pesticides through catchments which made it also a non-point source pollution model. For the model to run, it requires input data such as DEM, land use, soil maps and hydrometereological data. SWAT divides the basin into sub basins using digital elevation model and then each sub basin is further discretised into hydrological response units based on soil and land use information. Simulation of soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices will carry for each HRU and then aggregates for the sub basin by a weighted average.

The two major components of watershed hydrology are land phase and routing phase. The land phase controls the quantity of water, sediments, nutrients and pesticide loadings to the main stream in each sub basin whereas the routing phase controls the movement of water, sediments etc through the channel network to the catchment outlet (Arnold *et al.*, 2012). SWAT is an effective and useful tool in simulating the hydrologic process ranging from large river basins (Santhi *et al.*, 2001 and Gosain *et al.*, 2011) to small basins (Malunjkar *et al*., 2015 and Leta *et al*., 2016). SWAT is one of the promising model for continuous simulations in predominantly agricultural watersheds (Borah and Bera 2003).

SWAT model uses water balance equation for simulating hydrologic cycle or water balance is the driving force behind the simulations of SWAT (Neitsch *et al*., 2011) as shown below:

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

where,

SW_t = Final soil water content (mm H_2O),

SW_o = Initial soil water content on day i (mm H_2O)

R_{day} = Amount of precipitation on day i (mm H_2O)

Q_{surf} = Amount of surface runoff on day i (mm H_2O)

E_a = Amount of evapotranspiration on day i (mm H_2O)

w_{seep} = Amount of water entering the vadose zone from the soil profile on day i (mm H_2O)

Q_{gw} = Amount of return flow on day i (mm H_2O).

Preparation of input datasets:

The digital elevation model was prepared in ArcGIS 10.22 by digitizing the toposheet with 20m contour interval. Land use map derived from the LISS (III) imagery of IRS P6 satellite of 2008 was used for this study. The Soil map and the morphological characteristics of the soil collected from the Directorate of Soil Survey and Soil conservation of Kerala State were used. Meteorological data was obtained from Regional Agricultural Research Station, Pattambi, Kerala Agricultural University, IMD and Water Resources Department, Government of Kerala. Stream flow data for Pulamanthole gauging station was collected from CWC and Water Resources Department.

Preparation of text files and tables:

Land use and soil look up tables are prepared in the format of ASCII text file. Two types of tables were prepared for the meteorological data such as gauge location's table and daily precipitation, temperature, wind speed, relative humidity and solar radiation tables. The statistical data required by the weather generator data file were prepared using excel sheet, pcpSTAT and dew02.exe.

SWAT Model set up :

SWAT model requires spatial data sets such as DEM, land use and soil maps. It also requires meteorological data such as precipitation, temperature, relative humidity, solar radiation and wind speed. The methodology for SWAT model set up was shown in Fig B. Initially, the ArcSWAT project should be created where

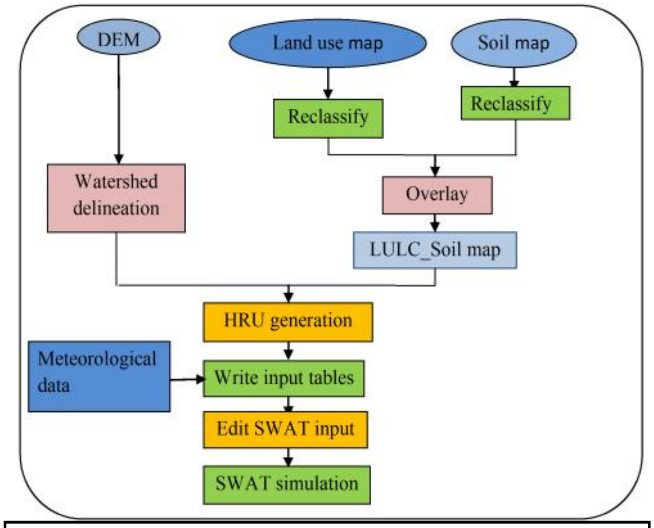

Fig. B : Flow chart for SWAT model set up

all the geodatabase will be stored. Using digital elevation model and choosing outlet watershed delineation is done by the model. Then by using land use map, soil map and slope map which is derived from the DEM, HRU's are created. HRU definition allows to specify criteria used in determination of HRU distribution and final HRU definition report will be created by the model. In "write input tables" menu, the weather stations command is used to load the weather stations locations. Weather Data Definition dialogue box allows user to feed data regarding rainfall, temperature, relative humidity, solar radiation and wind speed. The write SWAT input tables command act as interface to manage the creation of ArcSWAT geodatabase tables which stores values for SWAT input tables. Then SWAT Simulation menu allows the user to finalize the input set up for the model and to run the SWAT model.

Sensitivity analysis, calibration and validation:

Sensitivity analysis enables understanding the behaviour of the system and also evaluates the applicability of model (Van Griensven *et al.*, 2006). Sensitivity analysis, calibration and validation were done in SWAT-CUP. Since the watershed taken for study is ungauged one and hence calibration was done for Kunthipuzha basin which is nearby and having similar characteristics with study area. By using the calibrated parameters, the model was run for the study area. The model was run from 1997-2011 with a 3 year warm up period. The model was calibrated using observed daily flow records at pulamanthole gauging station for a 7 year period starting from 1st January 2000 to 31st December 2006 and validated from 1st January 2007 to 31st December 2009. Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970) and co-efficient of determination are used to evaluate the hydrological goodness of fit.

RESULTS AND DISCUSSION

The results obtained from the present study with relevant discussion have been summarized in the following sections.

Sensitivity analysis:

Sensitivity analysis was done to reduce the calibration effort. Using global sensitivity analysis in SWAT-CUP, the parameters which are found to be relatively more sensitive to stream flow are CN2, ALPHA_BF, ESCO, RCHRG_DP, SOL_Z, CH_K2 and SURLAG.

Calibration and validation:

The NSE and R^2 values after the calibration were 0.81 and 0.82 and during validation period, the values were 0.82 and 0.95, respectively. The results indicate "very good" performance of the model in simulating watershed.

From the above results as shown in Fig. 1 and 2, the model performance was very good in simulating stream flow. But the some of the peaks were under estimated by the SWAT model even after calibration. The reason may be the dependence of SWAT model entirely on empirical method such as "SCS-CN" method for calculating runoff and also may be due to the spatial

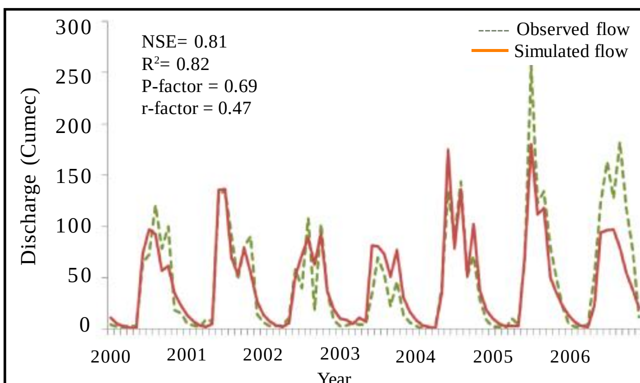

Fig. 1: Observed and simulated monthly stream flows at Pulamanthole after calibration

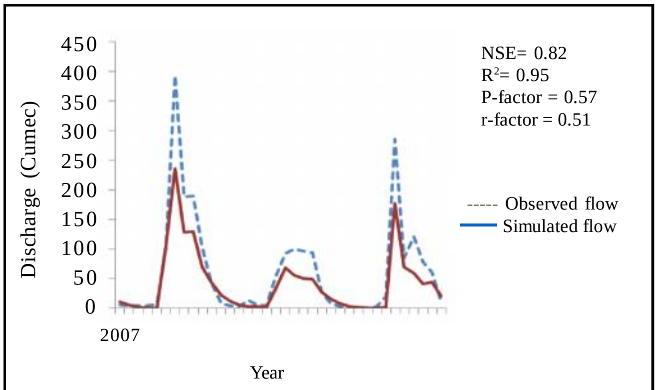

Fig. 2: Observed and simulated daily stream flows at Pulamanthole during validation period

variation of rainfall. These calibrated parameters are transferred to the study watershed and the model was run during a period 1997-2011.

Watershed delineation:

The elevation of the watershed ranges from (-)1 m to 166 m with mean elevation of 58.71 m and standard deviation of 36.78 m. The mean elevation of the 13 sub watersheds ranges from 25.2 to 95.6 m. The watershed delineated by the model for Valancheri watershed was shown in Fig. 3.

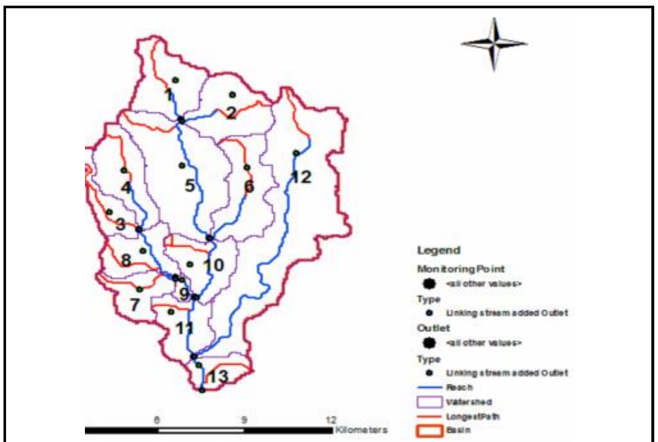

Fig. 3: Watershed delineated by the SWAT model for Valancheri watershed

HRU analysis:

Major land use types developed in the watershed are rice, various plantations, barren area, forest and urban settlement. The swat land use and soil classification was shown in Fig. 4 and 5. The soils are moderately to fine grained soils.

The annual water balance components for different years were shown in Fig. 6. Surface runoff is the major component followed by Ground water and ET. Deep aquifer recharge is very low from the watershed.

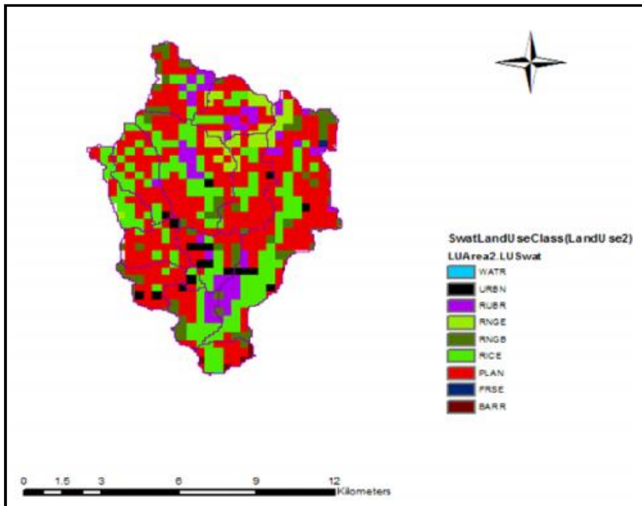

Fig. 4: SWAT land use classification for Valancheri watershed

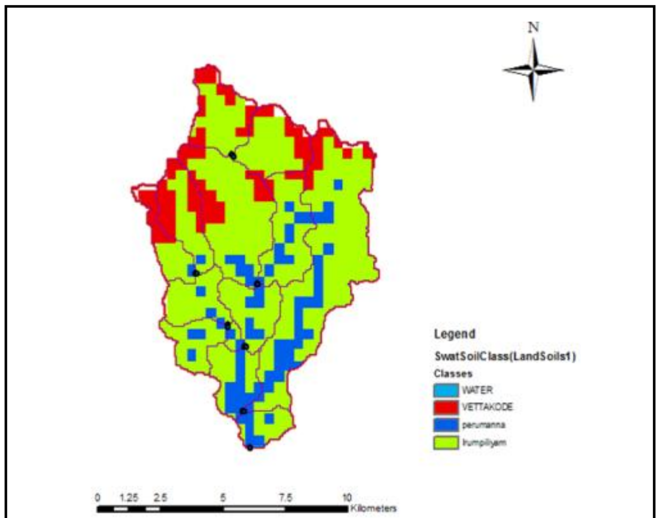

Fig. 5: SWAT soil classification for Valancheri watershed

The annual water balance components of the study area for different years were shown in Fig 6. The figure indicates that there is a considerable variation in water balance components from year to year. This can be vital information for water resource managers for planning water conservation structures in that area.

Fig. 6: Annual water balance components for different years

Conclusion:

Judicious conservation of water resources at micro watershed level is essential to reduce all kinds of water crisis. Physically based distributed watershed models are powerful tools in modeling water balance components on both spatial and temporal scale. Models should be calibrated before applying them for assessing hydrologic processes which can be possible for only gauged watersheds. But most of the basins in the world are ungauged and we cannot exempt those geographical areas from the ambit of scientific water management. These problems in terms of calibration for ungauged basins can be overcome by using regionalization technique. This study envisaged to assess the hydrologic processes of a small ungauged watershed at micro watershed scale. It was found that hydrologic processes such as ET, surface runoff, lateral flow and base flow were different within various micro watersheds. Using the predicted water balance components, water resources development plans of micro watersheds can be formulated effectively and scientifically. Surface runoff and base flow were the major components of the water yield of the stream channel; lateral flow component was relatively very less. Base flow during the summer period was very low and this highlights the need of augmenting deep percolation component in the watersheds. More recharge measures will help in increasing the base flow during summer months. Reduction of surface runoff from sloping lands is also required from the point of view of water conservation and reduction in soil erosion. The study concludes that SWAT model can be effectively used in understanding the hydrologic processes at micro watersheds scale and this information can in turn be used in planning interventions to solve the water scarcity scenario of a region or locality.

Authors' affiliations:

K.K. Sathian, Kelappaji College of Agricultural Engineering and Technology, Tavanur, **Malappuram (Kerala) India** Email: erkksathian@gmail.com

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