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# HYDROLOGIC BEHAVIOUR OF HIGHLAND CATCHMENT IN HUMID TROPICAL REGION USING QSWAT MODEL

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## ABSTRACT
Water resources planning and management of a region requires an understanding of the water balance in the region. The Soil and Water Assessment Tool (SWAT) with QGIS interface (QSWAT) has been used here to arrive at the water balance components in the Palapuzha watershed of Valapattanam river basin in Kerala. Valapattanam river drains an area of 1867 sq.km. with 456 sq.km. area in Karnataka State. The river basin receives an average annual rainfall of 3600 mm. The Palapuzha watershed drains an area of 237.25 sq.km with an average annual rainfall of 4562 mm. The QSWAT model has been calibrated and validated using data for a period of eight years (2000-2007) for which both rainfall and streamflow data are available. The model was successful in simulating monthly streamflow during the calibration and validation periods with Nash Sutcliffe efficiency and correlation co-efficient greater than 0.75 and percent bias less than 10%, showing that the model is very good for predicting streamflow in Valapattanam river basin. This calibrated model was used to arrive at the different water balance components in the Palapuzha watershed. The results obtained will be useful for the sustainable development and planning of the water resources system in the highland humid tropical watersheds.

**KEYWORDS**: Highland catchment, water balance, QSWAT, Valappattanam river.

## 1. INTRODUCTION
Planning and development in land and water resources management are evolving towards complex, spatially explicit regional assessments. This would be addressed with distributed models that can compute runoff at different spatial and temporal scales. Hydrologic models with spatial structure are being increasingly based on DEM or DTM (Moore et. al., 1991). The Soil and Water Assessment Tool (SWAT) which uses QGIS as the user interface (QSWAT) was used in this study. SWAT has been successfully applied with good results for watersheds without any monitoring data as well as for impact study related to land use, climate change etc. (Gassman et. al., 2007; Kaur et. al., 2004; Tripathi et. al., 2003; Chaplot et. al., 2004). Here an attempt is made to check the feasibility of the SWAT model for application in a highland watershed in northern Kerala, so that SWAT model could be applied to watersheds in similar area for water resources management.

## 2. MATERIALS AND METHODS

### Study Area
The Valapattanam river originates from Brahmagiri reserve forest in Karnataka at an elevation of 1350m above mean sea level. The main length of the river stream is 110 km. The river flows through Kannur district in Kerala and ends in Lakshadweep Sea. Major tributaries are Irikkur river, Sreekantapuram river, Bavali river, Veni river, Barapole river and the Aralam river. The catchment area upto the river gauging station at Palapuzha located at 11° 56' 30" N latitude and 75° 44' 00" E longitude and maintained by Water Resources Department of Kerala State is considered for this study. This catchment area named as Palapuzha watershed with an area of 237.25sq.km, is on the Bavali tributary of Valapattanam river. The Palapuzha watershed receives an average annual rainfall of 4562mm. The average elevation of the watershed is 501m above mean sea level. Figure 1 gives a view of the Palapuzha watershed in the Valapattanam river basin. More than 60% of the topographical area in the watershed is having a slope greater than 20%.

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**SWAT Model**

Soil and Water Assessment Tool (SWAT) is a physically based model which requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modelled by SWAT using this input data. SWAT can be used for modelling watersheds with no monitoring stream gauge data (Gassman et. al., 2007). The relative impact of alternative input data – changes in management practices, climate, vegetation etc. - on water quality or other variables of interest can be quantified using SWAT model (Hernandez et. al., 2000; Miller et. al., 2002; Heuvelmans et. al., 2005; Nelson et. al., 2005; Santhi et. al., 2006; Barcmort et. al., 2006). SWAT is a continuous time model and is not designed to simulate detailed single-event or flood routing. SWAT simulation is based on the water balance equation (i). Based on the user interface SWAT is named as ArcSWAT for ArcGIS interface and QSWAT for QGIS interface. Here QSWAT model, which is using an open source GIS ie., QGIS, is used for simulating streamflow in Palapuzha watershed.

**Model Data Inputs**

SWAT is a comprehensive model requiring a diversity of information. The first step in setting up a SWAT river basin simulation is to partition the basin into sub-units. The first level of sub-division is the sub-basin. The sub-basin delineation is defined by surface topography so that the entire area within a sub-basin flows to the sub-basin outlet. The land area in a sub-basin may be divided into Hydrologic Response Units (HRUs). These portions of a sub-watershed possess unique land use/management/soil attributes. The number of HRUs in a sub-basin is determined by a threshold value for land use and soil delineation in the sub-basin. The use of HRUs generally simplifies a simulation run because all similar soil and land use areas are lumped into a single response unit. SWAT2012 version using QGIS platform is used for the study. The spatially distributed data required for QSWAT include the Digital Elevation Model (DEM), soil data and land use data layers. The weather data and measured streamflow data are also required as input for the calibration and prediction purposes.

**Data Availability**

Daily rainfall data from two rain gauge stations, Palapuzha and Kottiyoor are available for a period of nine years (2000-2008). Streamflow data from Palapuzha gauging station is available from 1999 to 2007. The Digital Elevation Model (DEM) was downloaded from the USGS website. This DEM was used to delineate the river basin using automated delineation tool in SWAT. The entire river basin was divided into 13 sub-basins, each of which was again divided into several HRUs. A total of 38 HRUs were created. Landuse map was digitised from the survey of India topo sheet 49 M/9-1967, 49 M/13-1967 of 1:50000 scale. This land use map was compared with the land use map in the Indian WRIS site and necessary corrections made. Soil map of the river basin was purchased from the Soil Survey Organisation, Thiruvananthapuram. The same was registered and digitised using ArcGIS 10.1. Daily climate data observed from the Panniyoor gauging station by the Agriculture Department was collected for the period 1980-2015. The weather generator input file contains the statistical data needed to generate representative daily climate data for the sub-basins. In the present study, a weather generator input file was created from the data record for 36 years from the weather station at Panniyoor.

**Model Application**

In order to apply SWAT model to the Palapuzha watershed of Valapattanam river basin, the major steps involved are: 1) data preparation, 2) river basin and sub-basin delineation, 3) HRU definition, 4) Sensitivity analysis and 5) Model calibration and validation.

The precipitation data files for the calibration period (2000-2004) and validation period (2005-2007) were created for the observed data in the format specified in SWAT. The spatial data sets required were projected to the same projection, WGS_1984_UTM_ZONE43N using ArcGIS 10.1. DEM was used to delineate the watershed and to analyse the drainage pattern of the land surface terrain. The spatial data on land use/land cover were reclassified into SWAT land cover/plant types. User defined soil types were added to the soil database and the spatial soil data were linked to the appropriate types. The Multiple HRU definition suggested by the SWAT user's manual - 20 percent land use, 10 percent soil and 20 percent slope threshold – was applied in the study. The parameter sensitivity analysis was done for the selected watershed using SWATCUP software. Eighteen

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hydrologic parameters pertinent to water flow (SWAT2005 user's guide, 2007) were tested for sensitivity for the simulation of streamflow in the study area. The top ranked two parameters alpha_bf (base flow recession constant) and gw_revap (groundwater 'revap' coefficient) were used and manually adjusted for finally calibrating the model. The performance of the model is evaluated graphically and numerically. For graphical evaluation a linear as well as a scattered plot with the observed and simulated streamflow values are drawn and compared as shown in figures 2 to 5. The simulated flow values show good agreement with the observed data.

To check the predictive capability of SWAT model, Santhi et. al., (2001) and Coeffy et. al., (2004) recommended the use of the correlation coefficient ($R^2$) along with the Nash-Sutcliffe model efficiency coefficient ($N_{SE}$) (Nash and Sutcliffe, 1970) as a method to evaluate and analyse simulated monthly data. The $R^2$ value (equation (ii)) is a measure of the strength of the linear correlation between the predicted and observed values. The $N_{SE}$ value is the measure of the predictive power of the model given by equation (iii). In order to avoid certain problems associated with $R^2$, an index of agreement ($d$) given by equation (iv) has been introduced by Willmott, 1981. This statistics reflects the degree to which the observed variable is accurately estimated by the predictive variable; $d$ is not a measure of correlation in the formal sense but rather a measure of the degree to which a model's prediction are error free. A value of 1 for $N_{SE}$, $R^2$ and $d$ indicates a perfect match between simulated and observed values. Moriasi et. al., (2007) suggested a general performance rating for the recommended statistics for a monthly time step (table 1) for SWAT model. Comparison between the observed and simulated streamflow values for the period 2000 to 2007 indicated that there is a good agreement between the observed and simulated flows with higher values of Nash-Sutcliffe efficiency and lower values of *RSR*. The *RSR* is the root mean square error (*RMSE*) – observations standard deviation ratio; the *RSR* is calculated as the ratio of the *RMSE* and standard deviation of measured data, as given by equation (v). Percent bias (P*BIAS)* measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of *PBIAS* is 0.0, with low magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. *PBIAS* is calculated using equation (vi).

The calibrated and validated model predictive performance statistics is summarised in table 2. To arrive at the hydrological behaviour of the watershed the different water balance components was obtained using the calibrated model. Average value for the different components of the hydrologic cycle for the entire study period (2000-2007) is given in figure 6. It is found that the total flow is about 80% of the total precipitation, of which 70% is surface runoff, 30% is the baseflow. 13% of total precipitation is lost as evapotranspiration, 16% as percolation and remaining 0.01 as deep recharge.

**Figure**:

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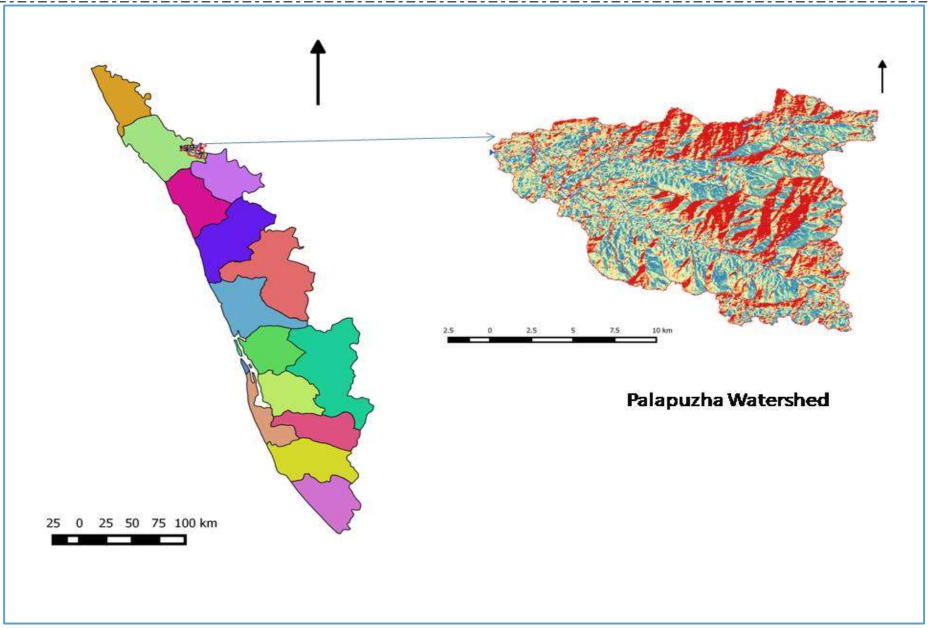


*Figure 1 Location map of Palapuzha watershed*

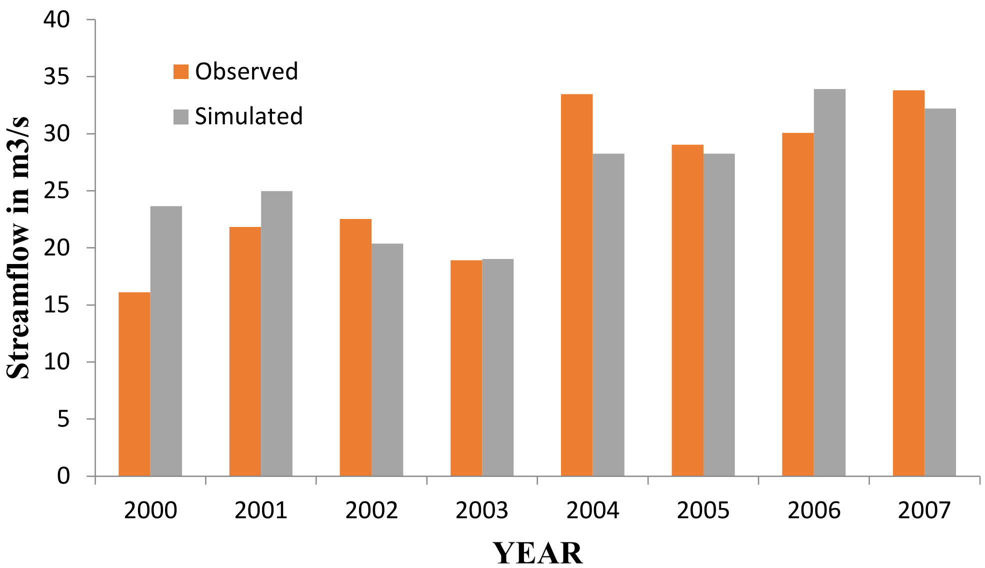


*Figure 2 Time series of Annual streamflow – Observed and Simulated*

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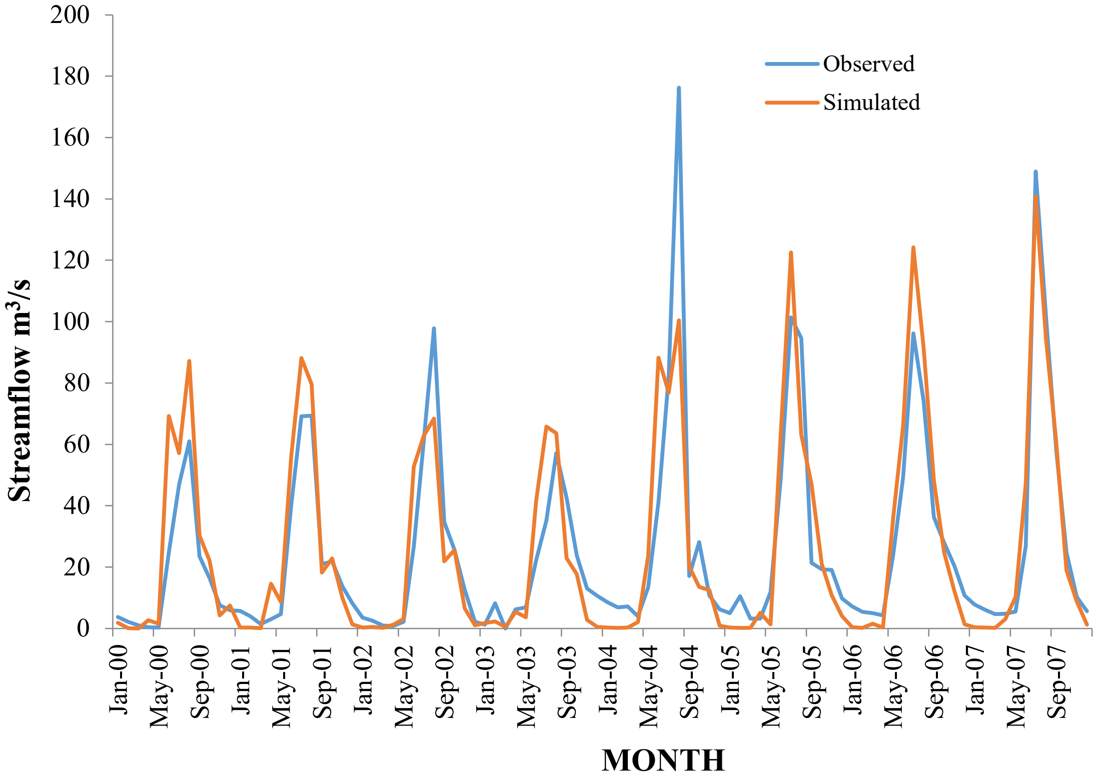


*Figure 3 Time series of Monthly streamflow – Observed and Simulated*

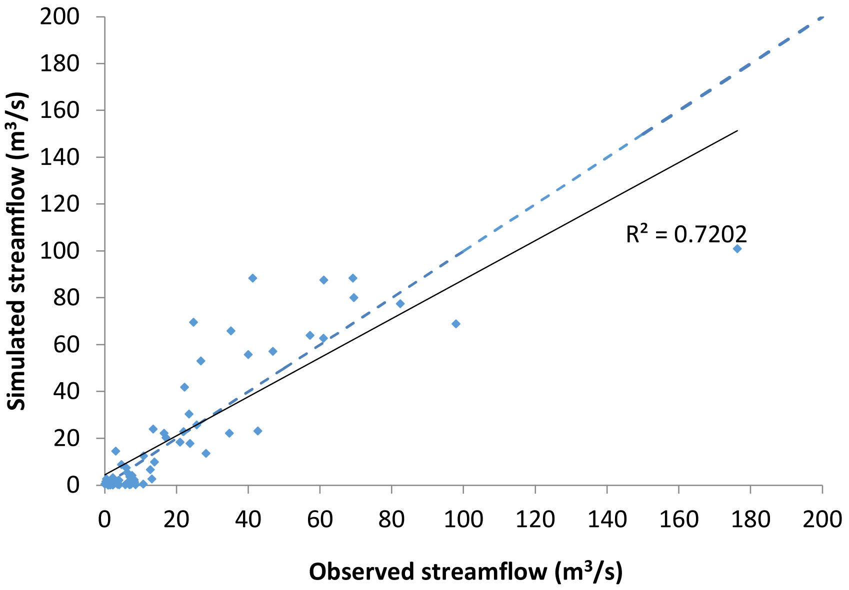


*Figure 4 Scatter plot of Observed and Simulated Monthly streamflow – calibration period (2000-2004)*

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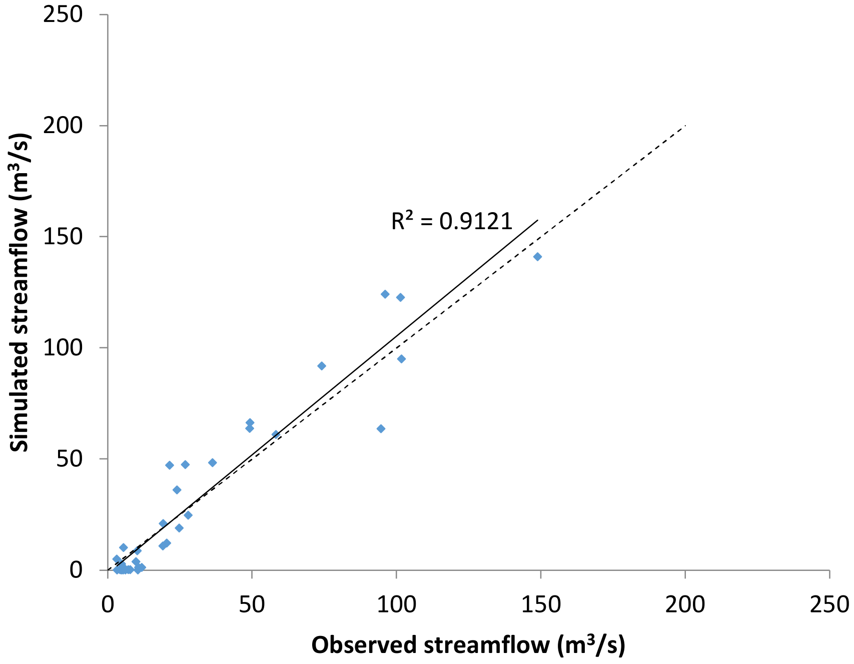


*Figure 5 Scatter plot of Observed and Simulated Monthly streamflow – validation period (2005-2007)*

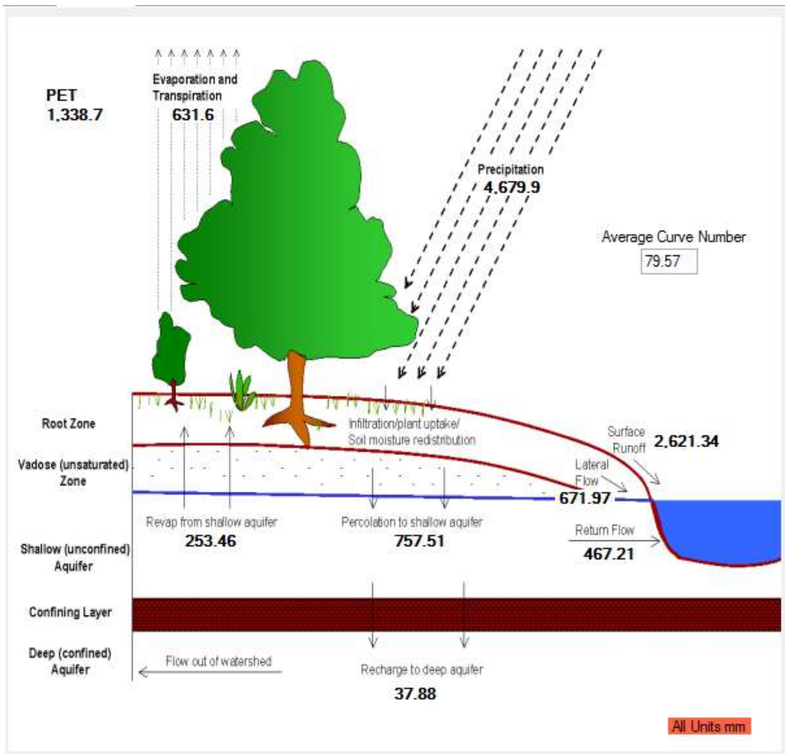


*Figure 6 Pictorial representation of water balance components of Palapuzha watershed for 2000-2007*

## 3. RESULTS AND DISCUSSION

QSWAT model was calibrated and validated with the observed data for a period of eight years (2000-2007) for

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the Palapuzha watershed in Valapattanam river basin of Kerala State. Model calibration was done using SWATCUP software and finally adjusted manually. The top two sensitive parameters alpha_bf and gw_revap are alone considered here for calibrating the model. The model results were then compared with the observed data to arrive at the statistical values (table 2) for the model performance, as well as represented graphically in figures 2 to 5. The Nash-Sutcliffe coefficient ($N_{SE}$), the correlation coefficient ($R^2$), index of agreement ($d$), the *RSR* and the percent error (*PBIAS*) obtained are well within the limit specified by Moriasi et. al., (2007). This shows that the model is capable to predict streamflow with very good accuracy.

Analysing the data for the period 2000 to 2007 it is observed that on an average about 80% of the total precipitation is flowing through the streams, 17% is percolated to the aquifers and 13% is lost as evapotranspiration. 70% of the total streamflow is surface runoff and 30% is the groundwater contribution. Average annual precipitation in the watershed is 4679.9mm, of which 2621.4mm is the surface runoff, 671.97mm is the lateral flow, 467.21mm is the return flow and 631.6mm is the evapotranspiration.

**Formulae:**

$$SW_t = SWo + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \qquad \text{(i)}$$

where,

| | | |
|---|---|---|
| $SW_t$ | = | soil water content at time t, |
| $SW_o$ | = | initial soil water content, |
| $t$ | = | time (in days), |
| $R_{day}$ | = | amount of precipitation on day i, |
| $Q_{surf}$ | = | amount of surface runoff on day i, |
| $E_a$ | = | amount of evapotranspiration on day i, |
| $w_{seep}$ | = | water percolation to the bottom of the soil profile on day i and, |
| $Q_{gw}$ | = | amount of water returning to the ground water on day i. |

$$R^2 = \frac{\left[\sum_{t=1}^{T} (Q_m^t - \overline{Q}_m)(Q_o^t - \overline{Q}_o)^2\right]}{\left[\sum (Q_m^t - \overline{Q}_m)^2 \sum_{t=1}^{T} (Q_o^t - \overline{Q}_o)^2\right]} \qquad \text{(ii)}$$

$$N_{SE} = 1 - \frac{\sum_{t=1}^{T} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T} (Q_o^t - \overline{Q}_o)^2} \qquad \text{(iii)}$$

$$d = 1 - \frac{\sum_{t=1}^{T} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T} \left(\left|Q_m^t - Q_o^t\right| + \left|Q_m^t - Q_o^t\right|\right)^2} \qquad \text{(iv)}$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{t=1}^{T}\left(Q_o^t - Q_m^t\right)^2}\right]}{\left[\sqrt{\sum_{t=1}^{T}\left(Q_o^t - \overline{Q_o}\right)^2}\right]} \quad \text{(v)}$$

$$PBIAS = \left[\frac{\sum_{t=1}^{T}\left(Q_o^t - Q_m^t\right)}{\sum_{t=1}^{T} Q_o^t} * 100\right] \quad \text{(vi)}$$

where

$N_{SE}$ = Nash-Sutcliffe coefficient,
$Q_o$= Observed discharge,
$Q_m$ = Modelled discharge,
$\overline{Q}\, o$ = mean observed discharge,
$Q^t$ = discharge at time $t$.

**Tables**:

***Table 1. Performance statistics of SWAT model for calibration and validation***

| Performance rating | RSR | $N_{SE}$ | PBIAS (%) |
|---|---|---|---|
| Very Good | $0.00 \le RSR \le 0.50$ | $0.75 < N_{SE} \le 1.00$ | PBIAS<10 |
| Good | $0.50 < RSR \le 0.60$ | $0.65 < N_{SE} \le 0.75$ | $10 \le PBIAS < 15$ |
| Satisfactory | $0.60 < RSR \le 0.70$ | $0.50 < N_{SE} \le 0.65$ | $15 \le PBIAS < 25$ |
| Unsatisfactory | RSR>0.70 | $N_{SE} \le 0.50$ | $PBIAS \ge 25$ |

***Table 2. Performance statistics of SWAT model for calibration and validation***

| Period | $N_{SE}$ | $R^2$ | d | RSR | PBIAS (%) |
|---|---|---|---|---|---|
| Calibration (2000-2004) | 0.70 | 0.72 | 0.92 | 0.55 | -3.37 |
| Validation (2005-2007) | 0.89 | 0.91 | 0.97 | 0.34 | -1.99 |

## 4. CONCLUSION

Palapuzha watershed draining an area of 237.25sq.km, in the Valapattanam river basin of Kerala State was selected to study the hydrologic behaviour of highland catchments in humid tropical region. On the basis of the high statistical values obtained for the model predictive performance, QSWAT model is found to be very good in predicting streamflow in humid tropical highland catchments. The average annual precipitation in Palapuzha watershed is 4679.9mm. Of which, 80% flows through the streams, 17% infiltrates to the ground and 13% is lost as evapotranspiration. 70% of the streamflow is surface runoff and 30% is the baseflow. About 65% of the watershed area is having slope greater than 20%, which resulted in excess runoff. This study reveals that the open source model QSWAT is a very good tool for assessing the hydrologic behaviour of highland watersheds in humid tropical region for use in planning and development projects.

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