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**Research Article**

# Simulation of streamflow using soil and water assessment tool (SWAT) in Meenachil river basin of Kerala, India

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**Abstract:** The main objective of the study was to test the performance and feasibility of SWAT 2005 model for prediction of streamflow in Meenachil river basin, Kerala. The model was calibrated and validated for three gauging stations, viz., Peroor, Pala and Cheripad. The model was autocalibrated for a period of 13 years (1982 – 1994) using Swat Cup software. The SuFi2 algorithm in Swat Cup was adopted for autocalibration of the model. The calibrated model was validated for the three gauging stations for a period of 10 years (1995 – 2004). The landuse map used for the calibration period was for the year 1990 and that for the validation period was for the year 2000. The simulated monthly streamflow has Nash Sutcliffe efficiency value of 0.80, 0.78 and 0.80 for the calibration period for the Peroor, Pala and Cheripad stations respectively. The model was successful in simulating streamflow during validation period as indicated by Nash Sutcliffe efficiency value of 0.75, 0.78 and 0.80 and $R^2$ value of 0.84, 0.83 and 0.85 respectively for Peroor, Pala and Cheripad stations. The model results in good performance showing that it is feasible for predicting streamflow in Meenachil river basin under changing landuse and climate conditions.
**Keywords**: SWAT2005, Swat Cup, SuFi2 algorithm, Meenachil river basin .

## INTRODUCTION

Meenachil river basin suffers from water scarcity during six months in a year. The available land and water resources are to be effectively utilized to improve the livelihood and socio economic conditions of the inhabitants. The existing land and water resources system of the area is adversely affected by the rapid growth of population and change in landuse/landcover. There is a need for hydrological research in the Meenachil river basin that can support improved catchment management programs which can better safeguard degradation of soil and water resources in the area. The lack of decision support tools and limitation of data concerning weather, hydrological, topography, soil and landuse are factors that significantly hinder research and development in the area. The decision support tools are the various hydrological and erosion models. Some of the watershed models developed during the last two decades are WMS (Watershed Modeling System), CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems), EPIC (Erosion Productivity Impact Calculator), AGNPS (Agricultural Non Point Source model), SWAT (Soil and Water Assessment Tool) and HSPF (Hydrologic Simulation Program – Fortran). Many of these models are applied for runoff and soil loss prediction, water quality modeling, landuse change effect assessment and climate change impact assessment. Among these models, physically based distributed model SWAT is a well established model for analyzing the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds. Only a few applications of SWAT model are made to Kerala conditions [1, 2, 3]. The main objective of the present study was to test the performance and feasibility of the SWAT2005 model for prediction of flow in Meenachil river basin of Kerala.

## STUDY AREA

The Meenachil river basin in Kerala encompasses approximately 1272 $km^2$ of drainage area, extending from Vagamon in the east at an elevation of 1195 m above mean sea level to Vembanad lake on the southwest coast of India. It lies between 09º26'24" and 09º51'00" N and 76º 22'12" and 76º55'12" E. The mean annual rainfall of the catchment area is about 3510 mm. Figure 1 shows the drainage map of the Meenachil river basin with the locations of rain gauge and streamflow stations. The streamflow data at Peroor, Pala and Cheripad are used in the present study; areas of the sub basins covered by these stations are 768, 438 and 147 $km^2$ respectively.

## METHODOLOGY

The present study concerns the application of a physically based watershed model SWAT2005 in Meenachil river basin to examine the influence of topographic, landuse, soil and climatic condition on streamflow. Model application involved calibration, sensitivity and uncertainty analysis. For this the SuFi2 calibration and uncertainty algorithm in Swat Cup was used.

**SWAT Model Description**

The SWAT model is a watershed scale, continuous-time model with a daily time step. SWAT is capable of simulating long-term yields for determining the effect of land-management practices [4]. SWAT components include hydrology, weather, soil, temperature, sediment yield, agricultural management practices, nutrients, pesticides etc. SWAT simulation is based on the water balance equation (1).

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

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 $i$.

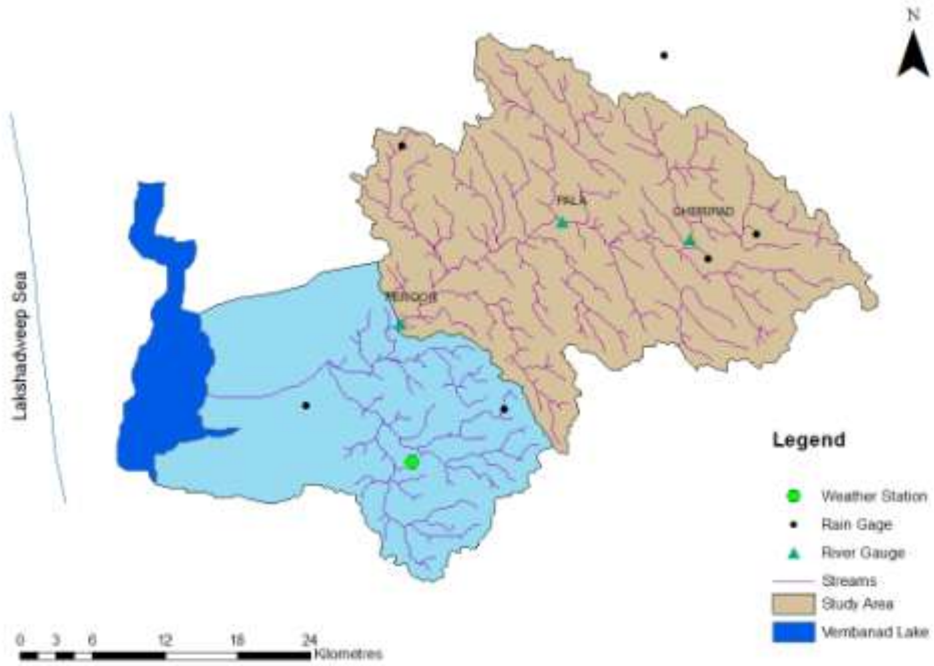


**Figure-1:Drainage Map of Meenachil River Basin**

For the estimation of surface runoff the SCS curve number (CN) is used in the model. This method uses two equations for runoff computation. The first relates runoff to rainfall and retention parameter as :

$$Q = \frac{(R - 0.2S)^2}{R + 0.2S} \qquad , R > 0.2S \quad (2)$$

where,

Q = daily surface runoff (in mm),
R = daily rainfall (in mm),
S = retention parameter, the maximum potential difference between rainfall and runoff (in mm) starting at the time the storm begins

The second equation relates retention parameter to curve number as :

$$S = 25.4\left(\frac{1,000}{CN} - 10\right) \quad (3)$$

where,
$CN$ = curve number ranging from $0 \leq CN \leq 100$

The SCS curve number depends on the infiltration characteristics of the soil, landuse and the antecedent soil moisture condition. The SCS defines three antecedent soil moisture conditions. I – dry (wilting point), II – average moist, and III – wet. The moisture condition I curve number is the lowest value that the daily curve number can assume in dry conditions. The standard values of curve number shown in SCS tables for various land cover and soils are based on antecedent soil moisture condition II. The standard values for curve number can be adjusted for drier or wetter antecedent conditions using the following equations :

$$CN_1 = CN_2 - \frac{20 \times (100 - CN_2)}{(100 - CN_2 + \exp[2.533 - 0.0636 \times (100 - CN_2)])} \quad (4)$$

$$CN_3 = CN_2 \times \exp[0.00673 \times (100 - CN_2)] \quad (5)$$

where,

$CN_1$ = moisture condition I curve number,
$CN_2$ = moisture condition II curve number,
$CN_3$ = moisture condition II curve number.

SWAT uses typical curve numbers for various soils with moisture condition II and a set slope of 5 percent. To adjust the curve number to different slopes an equation developed by William (1995) was used (equation 6).

$$CN_{2s} = \frac{(CN_3 - CN_2)}{3} \times [1 - 2 \times \exp(-13.86 \times slp)] + CN_2 \quad (6)$$

Where,

$CN_{2s}$= moisture condition II curve number adjusted for the slope,

$CN_3$ = moisture condition III curve number for default 5 percent slope,

$CN_2$ = moisture condition II curve number for default 5 percent slope,

$slp$ = average percent slope of the sub-watershed.

## Model Data Inputs

SWAT is a comprehensive model that requires a diversity of information. The first step in setting up a SWAT watershed simulation is to partition the watershed into subunits. The first level of sub division is the sub watershed. The sub watershed delineation is defined by surface topography so that the entire area within a sub watershed flows to the sub watershed outlet. The land area in a sub watershed may be divided into Hydrologic Response Units (HRUs). These portions of a sub watershed possess unique landuse/management/soil attributes. The number of HRUs in a sub watershed is determined by threshold value for landuse and soil delineation in the sub watershed. The use of HRUs generally simplifies a simulation run because all similar soil and landuse areas are lumped into a single response unit. SWAT2005 version using ArcGIS platform was used for the study. The ArcGIS platform provides the user with a complete set of GIS tools for developing, running and editing hydrologic and management inputs and finally calibrating the model. The spatially distributed data required for ArcSWAT include the Digital Elevation Model (DEM), soil data and landuse data layers either as shape files or grid data. Weather data and measured streamflow data are also required as input for calibration and prediction purposes.

### *Digital Elevation Model*

Topography was defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. For this the contour map of the area was prepared using ArcGIS and the DEM prepared. This DEM (Figure 2) was used to delineate the watershed using automated delineation tool in SWAT. The entire watershed was divided into 17 sub watersheds, each of which were again divided into several HRUs. A total of 307 HRUs were created.

### *Climate Data*

The climate data required are precipitation, maximum/minimum air temperature, wind speed, relative humidity and solar radiation. Values for these parameters may be read from records of observed data or they may be generated. The weather generator input file contains the statistical data needed to generate representative daily climate data for the subbasins. Climate data will be generated in two instances : when user specifies that simulated weather will be used or when measured data is missing. Here in this study a weather generator input file was created from 42 years data record of Puthupally weather station. Daily observed data for precipitation, maximum/minimum temperature, wind speed and relative humidity were used for the hydrologic simulation. The climate data for weather generation were collected from the Rubber Research Institute, Kottayam, Kerala.

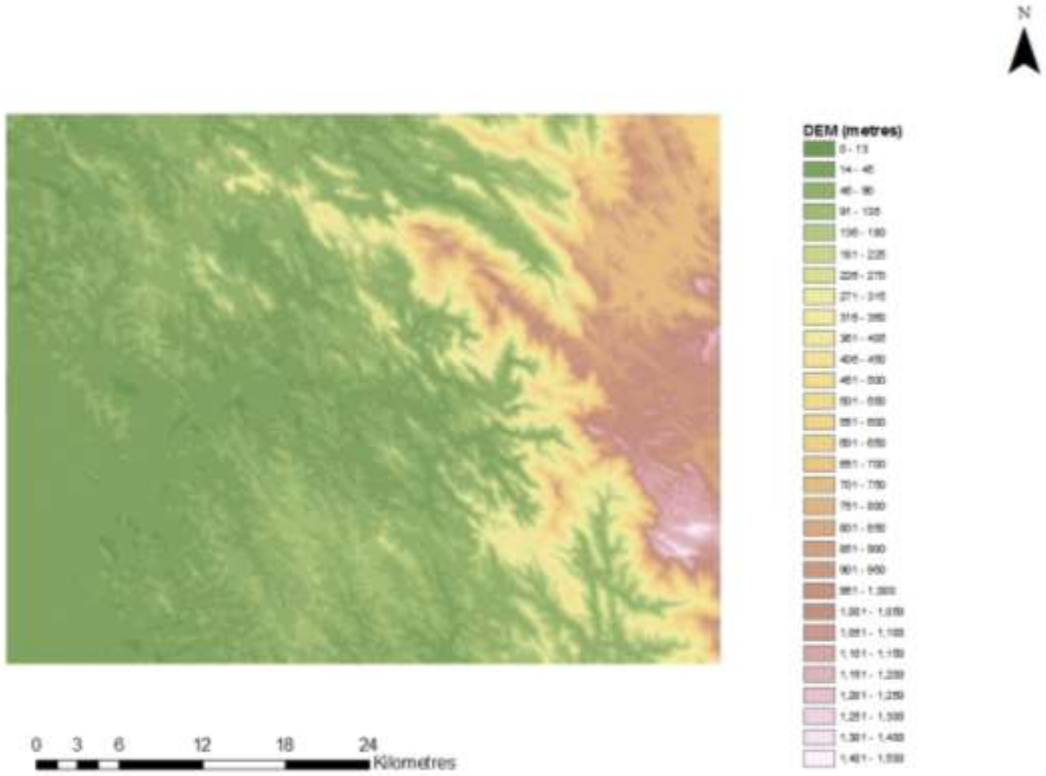


**Figure-2 :DEM Used For Watershed Delineation**

### *Streamflow Data*

Daily streamflow values for Peroor, Pala and Cheripad were collected from the Hydrology Division of Water Resources Department of Kerala State. These data were used for the calibration and validation of the model.

### *Landuse Data*

Landuse maps were prepared from the satellite imageries collected from NRSC. Landuse maps for the year 1990 (Figure 3) and 1999 (Figure 4) were prepared from Landsat imagery and IRS-1D imagery respectively to use with SWAT. Ground truth verification of the land cover were made at several places and map revised accordingly.

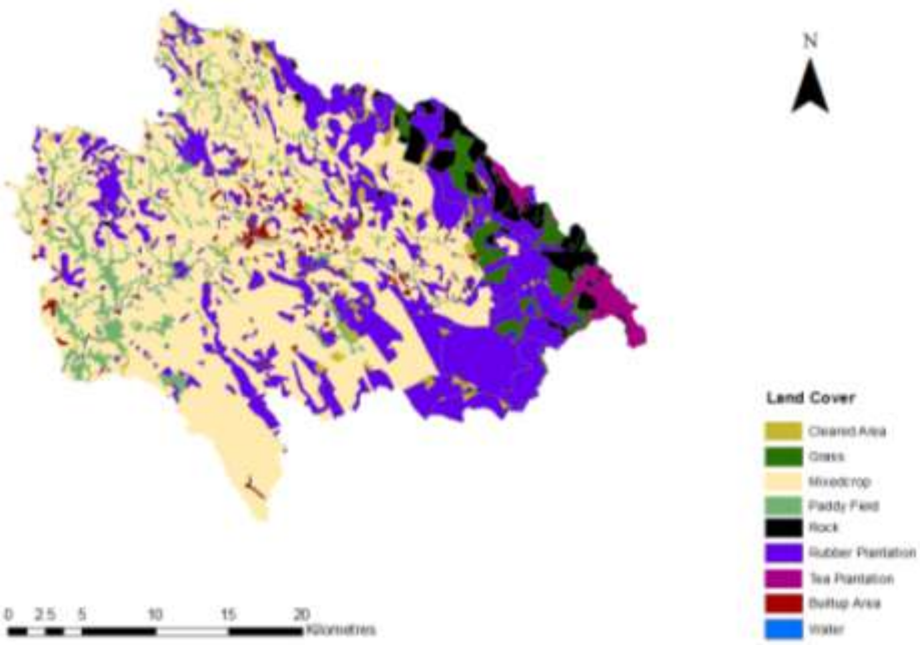


**Figure-3:Landuse Map Of Meenachil River Basin - 1990**

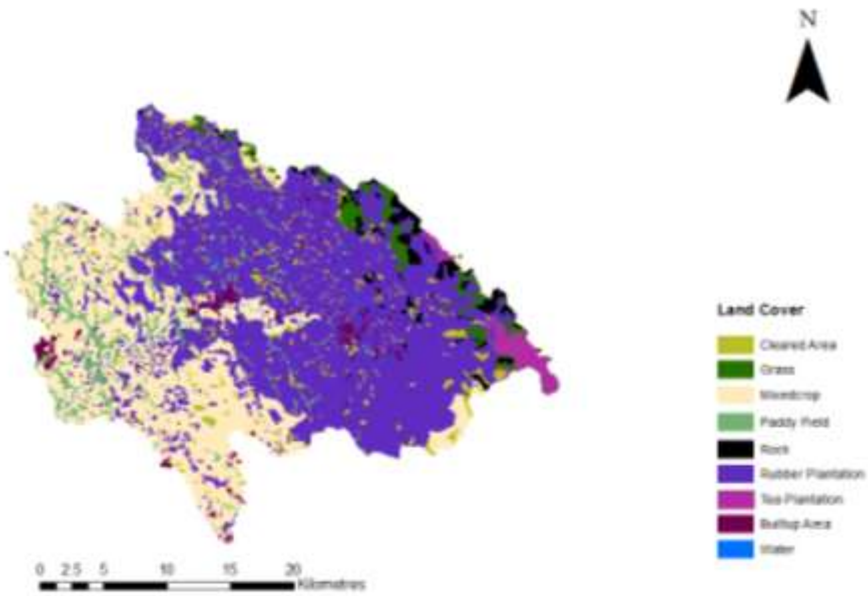


**Figure-4:Landuse Map Of Meenachil River Basin - 1999**

***Soil Data***

Soil data required for SWAT model was collected from the Soil Survey Organisation of Kerala State. The soil properties of different layers and the soil map were collected from the Soil Survey Organisation. The soil map was digitized and converted to grid map using ArcGIS 9.3 for using with SWAT. Major soils of the study area are Muthur, Arpookara, Kooropada, Lakkattoor, Koduman, Nellappara and Mavady series (Figure 5).

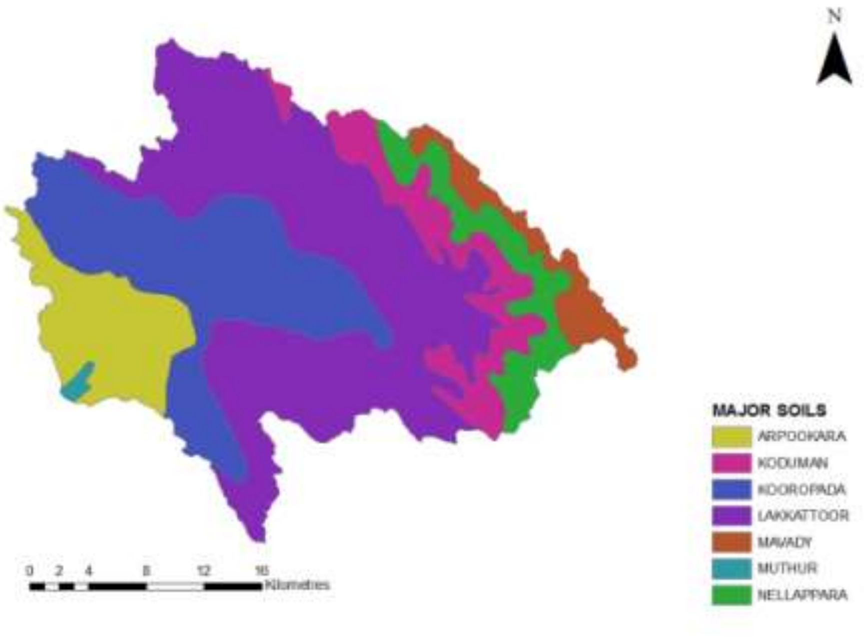


**Figure-5: Major Soils Of Meenachil River Basin**

**Model Application**

Inorder to apply SWAT model to the Meenachil river basin the major steps involved are : 1) data preparation, 2) watershed and sub watershed delineation, 3) HRU definition, 4) Sensitivity Analysis and 5) Model calibration and validation.

The precipitation and temperature data files for the calibration period (1979-1994) and validation period

(1992-2004) 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 9.3. DEM was used to delineate the watershed and to analyse the drainage patterns of the land surface terrain. The Landuse/Landcover spatial data were reclassified into SWAT landcover/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 ArcSWAT user's manual - 20 percent land use, 10 percent soil and 20 percent slope threshold – was applied for this study. The parameter sensitivity analysis was done for the whole watershed. Eighteen 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 ten parameters were used for calibrating the model. Swat Cup software was used for the calibration of the model. Sequential Uncertainity Fitting (SuFi-2) algorithm was used for calibration. The data for the period 1979 to 1994 were used for calibration of the model at three gauging locations, Peroor, Pala and Cheripad. For this period the landuse map of the area for the year 1990 was used. An independent precipitation, temperature, wind speed, relative humidity and streamflow data set (1992-2004) and landuse map for the year 1999 were used for validating the model. Periods 1979 to 1981 and 1992 to 1994 were used as "warm-up" periods for calibration and validation purposes, respectively. The warm-up period allows the model to get the hydrologic cycle fully operational.

**Evaluation of Model Performance**

Simulated data from the SWAT model can be compared statistically to observed data to evaluate the predictive capability of the model. Santhi and others [5] and Coffey and others [6] recommended using the correlation coefficient ($R^2$) together with the Nash-Sutcliffe model efficiency coefficient ($N_{SE}$) (Nash and Sutcliffe [7] as a method to evaluate and analyze simulated monthly data. The $R^2$ value is a measure of the strength of the linear correlation between the predicted and observed values. The $N_{SE}$ value, which is a measure of the predictive power of the model, is defined as :

$$N_{SE} = 1 - \frac{\sum_{t=1}^{T} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T} (Q_o^t - \overline{Q_o})^2} \qquad (7)$$

where,

$N_{SE}$ = Nash-Sutcliffe coefficient,
$Q_o$ = observed discharge,
$Q_m$ = modeled discharge,
$\overline{Q_o}$ = mean observed discharge,
$Q_t$ = discharge at time t.

A value of 1 for $N_{SE}$ indicates a perfect match between simulated and observed data values. A value of 1 for the $R^2$ also indicates a perfect linear correlation between simulated and observed data values.

In order to avoid certain problems associated with $R^2$ an index of agreement ($d$) (Willmott, 1981 & 1982), is presented (equation 8). This statistic reflects the degree to which the observed variable is accurately estimated by the predicted variable. $d$ is not a measure of correlation in the formal sense but rather a measure of the degree to which a model's predictions are error free. It varies between 0 (complete disagreement between predicted and observed values) and 1 (perfect agreement). It is a dimensionless statistics and its value should be evaluated based on (a) the phenomenon studied, (b) measurement accuracy and (c) the model employed.

$$d = 1 - \frac{\sum_{t=1}^{T} (Q_m^t - Q_o^t)^2}{\sum_{t=1}^{T} \left( \left| Q_m^t - \overline{Q_o} \right| + \left| Q_o^t - \overline{Q_o} \right| \right)^2} \qquad (8)$$

Moriasi et. al., [8] suggested a general performance ratings for recommended statistics for a monthly time step (table 1).

**Table 1. Performance Ratings of Recommended Statistics for Monthly Time Step for Streamflow**

| Performance Rating | RSR | $N_{SE}$ | PBIAS (%) Streamflow |
|---|---|---|---|
| Very good | 0.00 = RSR = 0.50 | 0.75 < NSE = 1.00 | PBIAS < ? 10 |
| Good | 0.50 < RSR = 0.60 | 0.65 < NSE = 0.75 | ? 10 = PBIAS < ? 15 |
| Satisfactory | 0.60 < RSR = 0.70 | 0.50 < NSE = 0.65 | ? 15 = PBIAS < ? 25 |
| Unsatisfactory | RSR > 0.70 | NSE = 0.50 | PBIAS = ? 25 |

In the above table the $N_{SE}$ given is the Nash-Sutcliffe model efficiency coefficient and it is computed as per equation 7. RSR is the (root mean square error) RMSE-observations standard deviation ratio. RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in equation 9.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y^{mean})^2}\right]} \quad (9)$$

Percent bias (PBIAS) 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 with equation 10 :

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim}) * (100)}{\sum_{i=1}^{n}(Y_i^{obs})}\right] \quad (10)$$

where

PBIAS is the deviation of data being evaluated, expressed as a percentage

$Y_i^{obs}$ is the observed value, $Y_i^{sim}$ is the simulated value and $Y^{mean}$ is the mean of observed values.

## RESULTS AND DISCUSSIONS

### *Uncalibrated Model Results*

Uncalibrated model results were obtained from a SWAT simulation using the default SWAT settings for parameters values before any calibration was performed. The uncalibrated simulation was performed for the period 1979-1994, with 1979 to 1981 as warm-up period. The $R^2$ for the correlation between simulated and observed streamflow were relatively high (0.75, 0.75 and 0.84) at the three sites, indicating a strong linear relationship between simulated and observed flows. Also the NSE values were greater than 0.5, which shows that the model is suitable for this watershed. But the PBIAS for two stations Pala and Peroor were -25.5% and -53.5% (ie., ≥ ±25%), which indicates an over prediction. On this basis, calibration of the model was required.

### *Model Calibration*

For calibrating the model a preliminary sensitivity analysis based on all the available climatic and hydrologic input data for the period 1979 to 1994 was performed on all the flow parameters. The first ten ranked parameters were selected, except curve number (CN2), for calibration purpose. SuFi2 algorithm in Swat Cup was used for calibration. The calibrated values for the parameters are given in table 2. The curve number (CN2) was adjusted for slopes. For slopes less than 5%, a curve number of 35 and for slopes greater than 15% a curve number of 93 were adopted.

**Table 2. SWAT flow sensitive parameters and fitted values after calibration using SuFi2**

| No. | Sensitive Parameters | Lower and Upper Bound | Final Fitted Value |
|---|---|---|---|
| 1 | Alpha_bf | 0 - 1 | 0.4375 |
| 2 | Gw-Delay | 0 - 500 | 18.75 |
| 3 | Gwqmn | 0 - 5000 | 1.525 |
| 4 | Gw_Revap | 0.02 - 0.2 | 0.19325 |
| 5 | Revapmn | 0 - 500 | 306.25 |
| 6 | Rchrg_dp | 0 - 1 | 0.6125 |
| 7 | Esco | 0 - 1 | 0.4625 |
| 8 | CH_N2 | 0 - 0.3 | 0.28125 |
| 9 | CH_K2 | 0 - 150 | 136.875 |

In the above calibrated parameters the Rchrg_dp is the most sensitive parameter. This was further adjusted manually for the three watersheds for better results. The values for this parameter arrived at for the Cheripad, Pala and Peroor watersheds were 0.40, 0.70 and 0.20 respectively. Comparison between the observed and calibrated streamflow values for thirteen years of simulation 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. Calibrated model predictive performance statistics for all the three streamflow sites on monthly flows is summarized in table 3 (a) & (b). Figure 6 shows the time series of observed and simulated monthly flows at Peroor station during calibration period.

**Table 3 Streamflow calibration results for Cheripad, Pala and Peroor using SuFi2**

(a)

| **Station** | **NSE** | **$R^2$** | **RSR** | **d** | **PBIAS (%)** |
|---|---|---|---|---|---|
| Cheripad | 0.80 | 0.84 | 0.45 | 0.93 | 14.2 |
| Pala | 0.78 | 0.80 | 0.47 | 0.93 | 8.4 |
| Peroor | 0.80 | 0.82 | 0.45 | 0.94 | -16.1 |

(b)

| YEAR | CHERIPAD | | | PALA | | | PEROOR | | |
|---|---|---|---|---|---|---|---|---|---|
| | $N_{SE}$ | $R^2$ | d | $N_{SE}$ | $R^2$ | d | $N_{SE}$ | $R^2$ | d |
| 1982 | 0.68 | 0.88 | 0.89 | 0.81 | 0.96 | 0.93 | 0.88 | 0.92 | 0.96 |
| 1983 | 0.77 | 0.86 | 0.92 | 0.85 | 0.92 | 0.95 | 0.59 | 0.83 | 0.91 |
| 1984 | 0.89 | 0.96 | 0.97 | 0.64 | 0.97 | 0.85 | 0.83 | 0.89 | 0.94 |
| 1985 | 0.73 | 0.94 | 0.89 | 0.73 | 0.96 | 0.89 | 0.84 | 0.92 | 0.94 |
| 1986 | 0.85 | 0.87 | 0.96 | 0.83 | 0.86 | 0.94 | 0.90 | 0.94 | 0.98 |
| 1987 | 0.79 | 0.86 | 0.93 | 0.77 | 0.89 | 0.95 | 0.77 | 0.89 | 0.95 |
| 1988 | 0.83 | 0.95 | 0.94 | 0.92 | 0.95 | 0.98 | 0.88 | 0.91 | 0.96 |
| 1989 | 0.86 | 0.92 | 0.96 | 0.64 | 0.99 | 0.86 | 0.95 | 0.98 | 0.99 |
| 1990 | 0.68 | 0.96 | 0.87 | 0.72 | 0.98 | 0.89 | 0.89 | 0.91 | 0.97 |
| 1991 | 0.91 | 0.96 | 0.97 | 0.87 | 0.97 | 0.97 | 0.96 | 0.98 | 0.99 |
| 1992 | 0.74 | 0.92 | 0.95 | 0.90 | 0.95 | 0.98 | 0.56 | 0.95 | 0.92 |
| 1993 | 0.95 | 0.96 | 0.99 | 0.81 | 0.99 | 0.96 | 0.66 | 0.94 | 0.93 |
| 1994 | 0.74 | 0.91 | 0.90 | 0.97 | 0.98 | 0.99 | 0.67 | 0.93 | 0.86 |

***Model Validation***

Streamflow collected during 1995 – 2004 for the stations Peroor, Pala and Cheripad were used for validating the predictive capability of the SWAT model applied to Meenachil river basin. The comparison statistics for observed and simulated monthly streamflow for the validation period are shown in table 4 (a) & (b). Figure 7 gives the time series of observed and simulated monthly streamflow during the validation period.

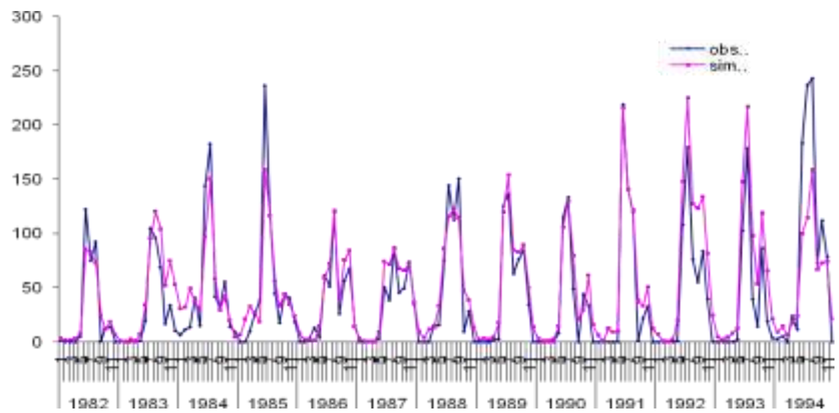


**Figure 6 Observed and simulated streamflow at Peroor for the calibration period.**

**Table 4 Streamflow validation results for Cheripad, Pala and Peroor using SWAT**

(a)

| **Station** | **NSE** | $R^2$ | **RSR** | **d** | **PBIAS (%)** |
|---|---|---|---|---|---|
| Cheripad | 0.80 | 0.85 | 0.45 | 0.93 | 19.6 |
| Pala | 0.78 | 0.83 | 0.47 | 0.95 | -19.5 |
| Peroor | 0.75 | 0.84 | 0.49 | 0.90 | 10.2 |

(b)

| YEAR | CHERIPAD | | | PALA | | | PEROOR | | |
|---|---|---|---|---|---|---|---|---|---|
| | $N_{SE}$ | $R^2$ | d | $N_{SE}$ | $R^2$ | d | $N_{SE}$ | $R^2$ | d |
| 1995 | 0.86 | 0.90 | 0.96 | 0.83 | 0.85 | 0.96 | 0.70 | 0.96 | 0.89 |
| 1996 | 0.95 | 0.96 | 0.99 | 0.77 | 0.95 | 0.94 | 0.79 | 0.87 | 0.92 |
| 1997 | 0.61 | 0.81 | 0.87 | 0.83 | 0.87 | 0.95 | 0.81 | 0.89 | 0.93 |
| 1998 | 0.61 | 0.72 | 0.88 | 0.75 | 0.83 | 0.94 | 0.74 | 0.94 | 0.90 |
| 1999 | 0.58 | 0.79 | 0.83 | 0.70 | 0.79 | 0.93 | 0.70 | 0.80 | 0.87 |
| 2000 | 0.93 | 0.96 | 0.98 | 0.73 | 0.95 | 0.95 | 0.63 | 0.68 | 0.87 |
| 2001 | 0.88 | 0.94 | 0.96 | 0.83 | 0.96 | 0.92 | 0.75 | 0.86 | 0.90 |
| 2002 | 0.61 | 0.67 | 0.86 | 0.79 | 0.91 | 0.95 | 0.65 | 0.77 | 0.91 |
| 2003 | 0.67 | 0.79 | 0.88 | 0.86 | 0.87 | 0.96 | 0.72 | 0.76 | 0.92 |
| 2004 | 0.61 | 0.90 | 0.84 | 0.54 | 0.82 | 0.81 | 0.78 | 0.88 | 0.93 |

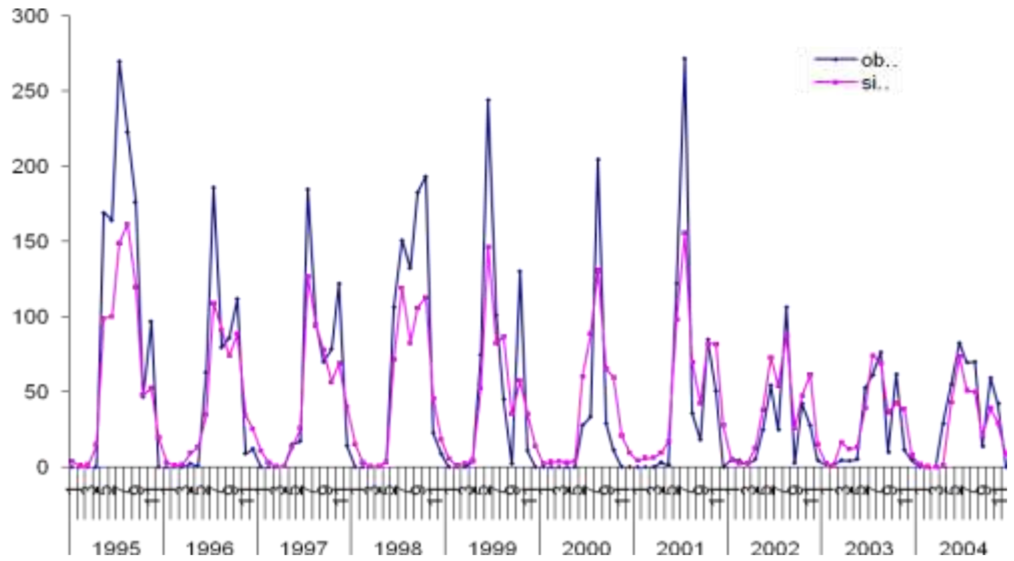


**Figure 7 Observed and simulated streamflow at Peroor for the validation period.**

## CONCLUSION

The SWAT2005 model was used to simulate streamflow in Meenachil river basin of Kerala State, India. The study objective was to determine whether the SWAT model could be used to simulate streamflow for a basin with humid tropical climate. SWAT model was successfully calibrated and validated using SuFi2 algorithm in SWAT CUP. The high $N_{SE}$ value and low *RSR* and *PBIAS* values rated the model very good for the humid tropical region. This good performance of the model makes it feasible for predicting streamflow in Meenachil river basin under changing landuse and climate conditions.

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