

# SWAT Modeling and Water Quality Analysis of Meenachil River, Kerala



P. V. Sujana and Anupama Surenjan

**Abstract** The Meenachil River is an important river serving Central Kerala. The rapid growth of population and change in land use have had an adverse effect on the river basin. A hydrological research in Meenachil River Basin (MRB) would aid in implementing an enhanced management program to prevent degradation of soil and water resources in the area. Soil and Water Assessment Tool (SWAT) modeling for streamflow has done in MRB for analyzing the water quality of the river. Using the SuFi2 algorithm in SWAT-CUP, the model was successfully calibrated and validated for Kidangoor gauging station. The model was calibrated during a ten-year period (1997–2006) and verified over a nine-year period (2007–2015). As reflected by coefficient of determination ( $R^2$ ) and Nash–Sutcliffe simulation efficiency (NSE) values, model predictions done remarkably efficient on monthly basis during the calibration and validation periods. The  $R^2$  and NSE for the simulated monthly streamflow are 0.79 and 0.77 for the calibration period, and 0.82 and 0.75 for the validation period. The calibrated model was used to study the effects of landscape, climate condition, and fertilizer application on sediment and nutrient loadings. From the investigation, it was observed that hydrological processes play an important role in the transport of pollutants and fertilizer which led to excessive nutrient loadings in the river. The model performs effectively, indicating that it can be used to estimate streamflow in MRB and provide knowledge about the water quality under various land scape and climate conditions.

**Keywords** Meenachil River · SWAT 2012 · SWAT-CUP · SuFi2 algorithm · Streamflow · Surface water quality

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## 1 Introduction

Meenachil River is the only river in Kerala, which has human settlement from origin to end of its flow. It originates at Vagamon in Western Ghats and flows through Kottayam District of Kerala state, India [1]. The rapid growth of population and change in land use have adversely affected the river basin. During six months of the year, the river basin experiences water scarcity. The increased cultivation of rubber plant in this particular area has severely impacted the environment due to higher runoff rate than the mixed crop, increased groundwater dependence during the summer, allowing the erosion cycle and the overflow of pesticides and fertilizers from the plantation [2]. The rising demand for water affects the natural water system and is considered as the primary cause of the degradation of water quality in the river. Agricultural activities have resulted in increased salinity, alkalinity, and water-logging problems in the area. Run-off from agricultural fields, industrial effluents, sewage from urban settlements, mining activities and over exploitation of groundwater, domestic and industrial pollution, combined with deforestation, use of pesticides and fertilizers have affected the river water quality extensively making water unfit for drinking. It was reported that the use of fertilizers has also affected groundwater quality in the basin [3]. A hydrological method is important to address and resolve the environmental issues occurring in this area.

Modeling tools help in understanding the complex interactions between the pollution source, the landscape, the nutrient cycle, climate, and the surface water quality. Numerous models have been developed to estimate streamflow and pollutant concentrations in streams and other water bodies. The current investigation is concentrated on the use of Soil and Water Assessment Tool (SWAT) modeling a physically based distributed model for nutrient simulation, sediment yields, and to analyze the impact of different land management practices on water quality [1]. This paper is focused in accessing the ability of SWAT version 2012 to simulate streamflow and associated nutrients and suggest alternative management practices in controlling pollution in Meenachil River of Kidangoor station, Kerala.

## 2 Materials and Methods

### 2.1 *Soil and Water Assessment Tool (SWAT) Model*

The SWAT model, a comprehensive, semi-distributed, continuous time, processed-based model [4–6], was developed in the 1990s by the United States Department of Agriculture (USDA). SWAT software is based on spatially semi-dispersed hydrological and water quality model, which is intended to find out runoff water, sediments, and nutrients from the mainstream watersheds to its outlet. The model is a particularly flexible software that has been utilized in various parts of the world to check and predict the impact of land use pattern and practices on water, fertilizer

yield, and sediments from farming activities in small to large basins with different land use, soils, and management scenarios, over an amount of time. The SWAT model can be used to create models to examine the effects of alternative decision making on water resource management and non-point source pollution in large river basins. It uses the concept of excess runoff mechanism and infiltration. It assumes that the runoff occurs every occasion the rainfall exceeds the rate of infiltration. Main components of the model include soil temperature and properties, weather, pesticides, plant growth, land management, nutrients, hydrology, and bacteria and pathogens. In SWAT, ArcGIS tool defines hydrological characteristics of the watershed and store-relevant spatial and tabular data, which can divide watershed into sub-basins for high-level spatial detail simulation. These small units called Hydrologic Response Units (HRUs) consist of homogeneous slope, soil characteristics, land use, and management. The HRUs represent percentages of the sub-watershed area [4].

The SWAT model simulates the hydrological cycle as indicated by Eq. (1) of water balance [6].

$$SW_t = SW_o + \sum (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \tag{1}$$

$SW_t$  stands for soil water content (final) (mm),  $SW_o$  for soil water content (initial) in day  $I$  (mm), and  $t$  for time (days). The proportion of precipitation on a given day is denoted by  $R_{day}$   $I$  (mm),  $Q_{surf}$  indicates the surface runoff in day  $i$  (mm),  $E_a$  indicates the amount of evapotranspiration in day  $i$  (mm),  $W_{seep}$  represents the water percolation to the bottom of the soil profile on day  $i$  (mm), and  $Q_{gw}$  represents the groundwater discharge in day  $i$  (mm). For sustainable management of water resources, the important parameter for the evaluation of the study area is the water yield. Sum of water leaving the HRU and entering the channel during the time step is defined as the water yield in that area [5]. Water yield within a watershed is evaluated by the model based on Eq. (2):

$$W_{yield} = Q_{surf} + Q_{gw} + Q_{lat} - T_{loss} \tag{2}$$

Here,  $W_{yield}$  represents the value of water yield (mm),  $Q_{gw}$  represents the contribution of groundwater to streamflow (mm),  $Q_{surf}$  indicates the surface runoff (mm),  $T_{loss}$  indicates the value of transmission losses (mm), and  $Q_{lat}$  represents the lateral flow contribution to stream (mm) and through bed transmission from tributary in the HRU.

The SWAT-simulated hydrological processes include infiltration, canopy storage, and surface. The processes in the soil involve drainage, return flow from shallow aquifers, lateral flow which transport water to the river, shallow aquifer recharge, and capillary rise from shallow aquifer into the root zone aquifer recharge which removes water from the system and evapotranspiration. Nutrient cycle for nitrogen and phosphorus is generated in SWAT. Two inorganic forms such as ammonium and

nitrate and three organic forms of nitrogen are simulated. Similarly, three inorganic and three organic forms of phosphorous are simulated by SWAT [7].

### **Nutrient simulation in SWAT**

The transport and transformation of nitrogen (N) and phosphorus (P) simulated in SWAT within an HRU are a function of nutrient cycles with inorganic and organic forms. N and P loss from the soil is assumed by plant absorption and surface runoff in SWAT. Simulated losses of N also occur in percolation below the root zone, in lateral subsurface flow, and by volatilization to the atmosphere. Movement of nitrate ( $\text{NO}_3\text{-N}$ ) in surface runoff, lateral subsurface flow, and percolation are computed as the product of the average soil layer  $\text{NO}_3\text{-N}$  concentration and the volume of water in each flow pathway. Soluble P lost through surface runoff is determined as a function of the P solution concentration in 10 mm of top soil, the surface runoff volume, and a partitioning factor [8].

## **2.2 Study Area**

Meenachil River is one among the significant rivers of Kottayam district in Kerala. It emerges from Western Ghats and flows through the taluks of Meenachil, Vaikom, and Kottayam. This then splits into number of tributaries before ending into Vembanad Lake. The river has a total length of 78 km and has a catchment area of 1272 km<sup>2</sup>, extending from Vagamon in the east at an elevation of 1195 m. The entire Meenachil watershed area geographically lies between 09° 26' 24" and 09° 51' 00" N latitude and longitude of 76° 22' 12" and 76° 55' 12" E. Total annual yield of the river is 2349 million m<sup>3</sup> out of which 1110 million m<sup>3</sup> has been used in every year [9]. The river has 47 sub-watersheds, 114 micro-watersheds, and 38 tributaries including major and minor ones. The Meenachil River Basin falls within a tropical climate region; high variations in elevation and proximity to the sea influence the climatic parameters. The temperature of the area varies in between 24 and 32 °C throughout the year [9]. The basin's average annual rainfall is 3510 mm. It is most available in the southwest (June–August) and northeast (October–December) monsoon seasons. Only 10% occurring throughout January to May (summer months) [1]. The MRB mainly comprises of precambrian metamorphic rocks which form a hilly background. Well-drained laterite soils are the most common soil type in the area. Riverine alluvium soils and forest soils can also be found in some areas. Rubber trees are cultivated throughout large areas of the river basin. Other crops such as spices and paddy are also grown in the river basin [9].

Eazon [10] studied the flow pattern of Meenachil River using Indicators of Hydrologic Alteration (IHA) software reflects the basins, ecological distress, quality issues, siltation, and weed growth. In the study, an alteration in flow pattern was observed. This indicates large-scale anthropogenic influence in the river which may be causing a slow death to the river by the same society which is very much dependent on it. Narayanan [11] studied the Ichthyofauna of Aymanam Panchayat, in Vembanad

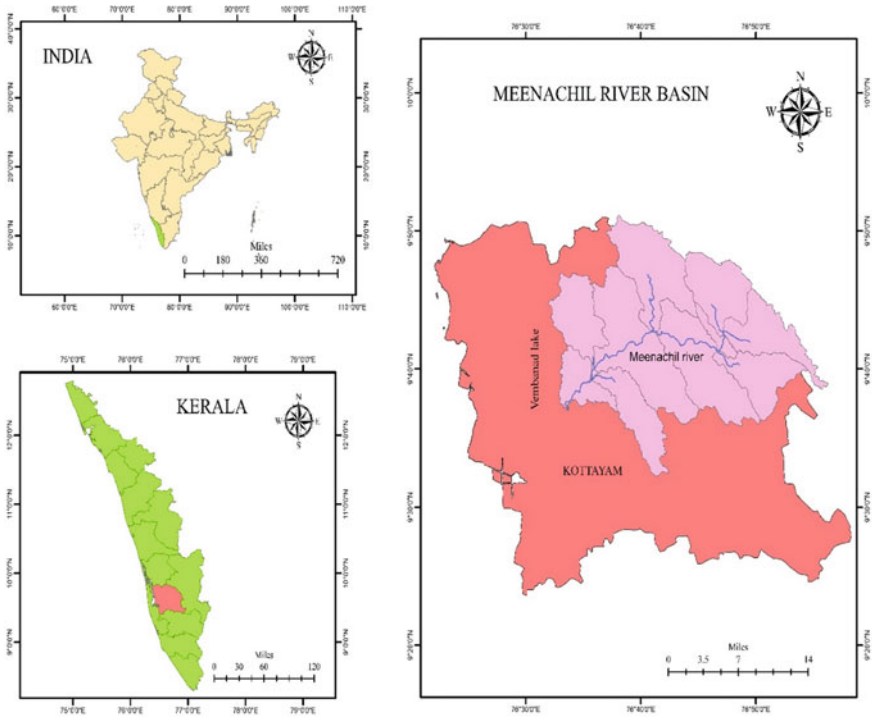
wetland in Kerala. The Meenachil River feeds the Vembanad wetland. Out of 34 freshwater species, nine were threatened. One exotic species also noted. Abhilash [12] conducted a study on an invasive weed using Geographical Information System at Kumarakom, the tributary system of the Meenachil River. The study reflected that nutrients, water depth, land use patterns, and associated species were the major factors responsible for the growth and spreading of this exotic weed. Meenachil River has an accumulation of toxic metals right before the monsoon season [9]. This is because the continuous discharge of sewage from the banking town areas of the river and erosion from the plantations along the basin are causing problems to the river. According to George [13], significant rise of total phosphorous in water and sediment indicates the contribution of leachate from widespread rubber plantations in the upland catchment area. Joseph [14, 15] found that the water in Pennar River, a branch of Meenachil is highly contaminated and not safe for drinking. Uncontrolled use of chemical fertilizers and pesticides, and unethical dumping of domestic wastes are the major causes of deterioration of water. Smitha et al. studied the algal diversity in Meenachil River [16]. Sixteen algal species were observed in the study. Vincy [17] studied the toxic microorganisms and compared the microbiological quality of the Meenachil River water. The pathogenic bacteria present in the river indicates that the bacteriological quality is poor in the river. It also indicates that raw sewage is being dumped into the river. The location map of the Meenachil River is shown in Fig. 1.

### 3 Data Collection

SWAT requires a variety of information. The spatially distributed data required for Arc SWAT include the Digital Elevation Model (DEM), soil data, and land use data layers either as shape files or grid data. For calibration and prediction purposes, weather data and observed streamflow data are also necessary.

#### 3.1 DEM (*Digital Elevation Model*)

Topography data are used to delineate a watershed into multiple sub-watersheds and also to calculate watershed/sub-watershed parameters such as slope and slope length. Digital Elevation model (DEM) represents the topography of an area. At a certain spatial resolution, it describes the elevation of any point in a particular area. As it contains the elevation information, it determines the possible directions of flow and physical characteristics of the watershed [18]. The DEM is extracted from the Shuttle Radar Topography Mission (SRTM) data which are of 90 m resolution, year 2014 downloaded from United State Geological Survey (USGS) (<https://earthexplorer.usgs.gov/>). This DEM shown in Fig. 2 was used to delineate the watershed using delineation tool in SWAT.



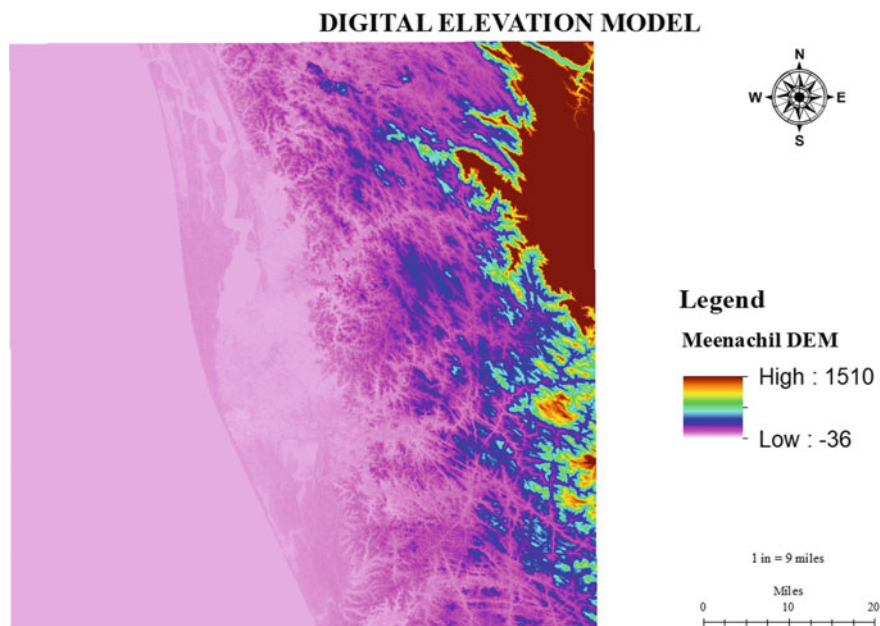
**Fig. 1** Location map of study area

### 3.2 Climate Data

The climate data required are precipitation and maximum/minimum air temperature. Daily observed data for precipitation, maximum or minimum temperature (1997–2015) were used for the hydrologic simulation. The temperature data and rainfall data of high resolution ( $0.25^\circ \times 0.25^\circ$ ) gridded dataset are collected from India Meteorological Department (IMD) <https://mausam.imd.gov.in/> for this study.

### 3.3 Land Use/Land Cover

The land use map of watershed is clipped from the land use map of India, spatial resolution 100 m [19]. Land use map gives the purpose of usage of each portion of study area. LULC classification is done in ArcGIS 10.3. The distribution of various land use/land cover classes in the study area is provided in Fig. 3. The study area comprises of nine different land use categories (Table 1).



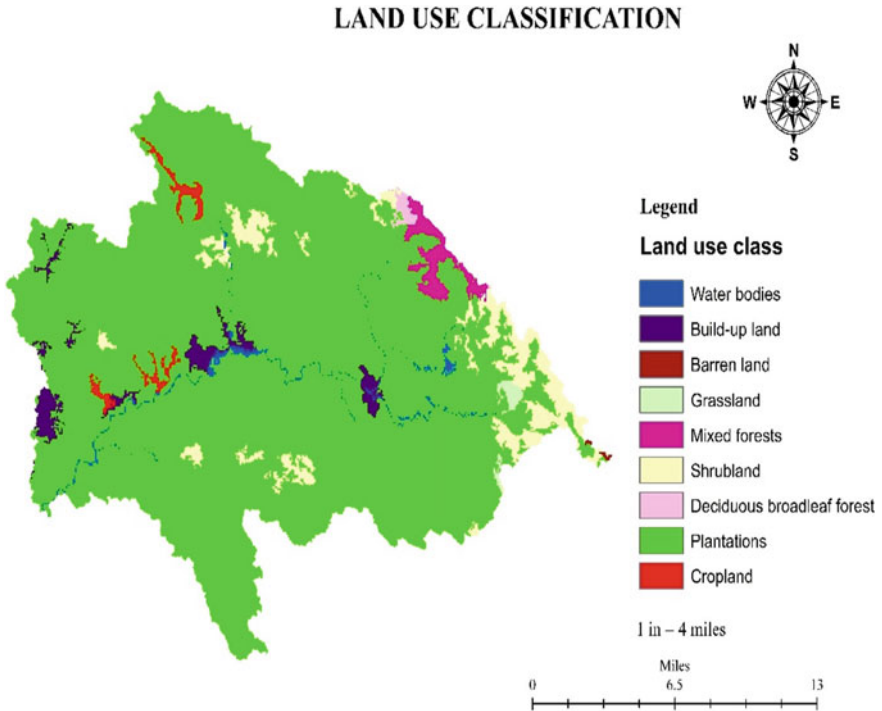
**Fig. 2** Digital elevation model

### **3.4 Soil Data**

The soil data are obtained (2005) from NBSS (National Bureau of soil survey and Land use planning). The shapefile of the study area extracted, clipped, and classified in Arc GIS 10.3. Meenachil basin consists of mainly three different types of soils (Table 2). Different soils having different properties like hydraulic conductivity, bulk density, available water capacity, structure, etc. Figure 4 represents the soil classification.

### **3.5 Streamflow Data**

The discharge data are collected from the Central Water Commission, India (CWC), via India-WRIS (Water Resources Information System) portal. The discharge data for Kidangoor gauge station for the time period 1997 to 2015 in monthly scale were collected for this study. <https://indiawriss.gov.in/wris/#/>.



**Fig. 3** Land use map of Meenachil River Basin-2005

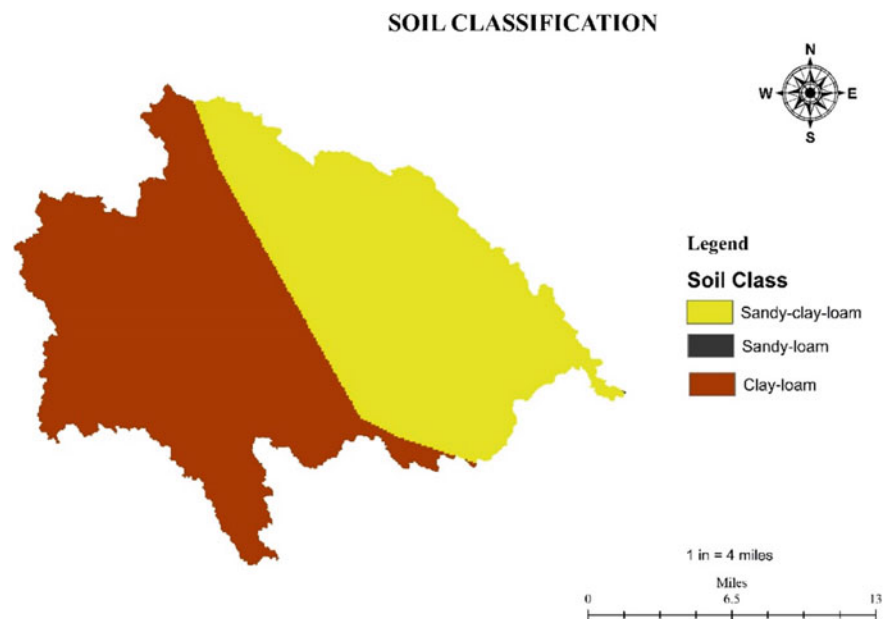
**Table 1** Land use/land cover categories

Land use type	Area (%) cover
Deciduous broadleaf forest	0.32
Crop land	0.87
Build-up land	2.06
Mixed forests	1.38
Shrubland	5.52
Barren land	0.04
Water bodies	0.91
Plantations	88.55
Grassland	0.35

**Table 2** Soil classification

Soil type	% Area
Sandy-clay-loam	46.007
Sandy-loam	0.004
Clay-loam	53.989





**Fig. 4** Major soils of Meenachil River Basin

### **3.6 Water Quality Data**

Monthly measured values of various water quality parameters of Meenachil River at Kidangoor station have been collected from Kerala Pollution Control Board (KPCB). Water quality parameters have been collected from India-WRIS (Water Resources Information System) portal also.

## **4 Model Application**

The major steps involved for the application of SWAT model to the Meenachil River basin are (1) data preparation, (2) watershed delineation, (3) HRU definition, (4) sensitivity analysis, and (5) model calibration and validation. The precipitation and temperature data files for the calibration period (1997–2006) and validation period (2007–2015) 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 10.3. Project setup has done to store necessary folders and databases during modeling. DEM was inserted for the delineation of the watershed and to understand the directions of flow. The land use/land cover spatial data were reclassified into SWAT land cover/plant types. User-defined soil types were added to the soil database. Multiple HRU definition suggested by the

ArcSWAT user's manual [20], threshold value of 5% land use, 20% soil, and 20% slope were applied for this study. Nine hydrologic parameters influencing water flow were tested for sensitivity for the simulation of streamflow in the study area. In order to calibrate the model, SWAT-CUP software was used. Sequential Uncertainty Fitting (SuFi-2) algorithm was used for calibration. SWAT was executed for a total simulation period of 19 years, which includes 1997–2006 as a calibration period and 2007–2015 as a validation period. Parameter adjustment has carried out only during calibration period. The validation process was accomplished for different time period by simply providing previously calibrated input parameters. Precipitation, temperature, and streamflow data set (1997–2015) and land use map of the year 2005 were used for the validation of the model.

## 5 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. The correlation coefficient ( $R^2$ ) together with the Nash–Sutcliffe model efficiency (NSE) coefficient 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 NSE value, which is a measure of the predictive power of the model, is defined as (Eq. (3)):

$$NSE = \frac{1 - \sum_i^n (\text{obs}_i - \text{sim}_i)^2}{\sum_i^n (\text{obs}_i - \text{sim}_{\text{mean}})^2} \quad (3)$$

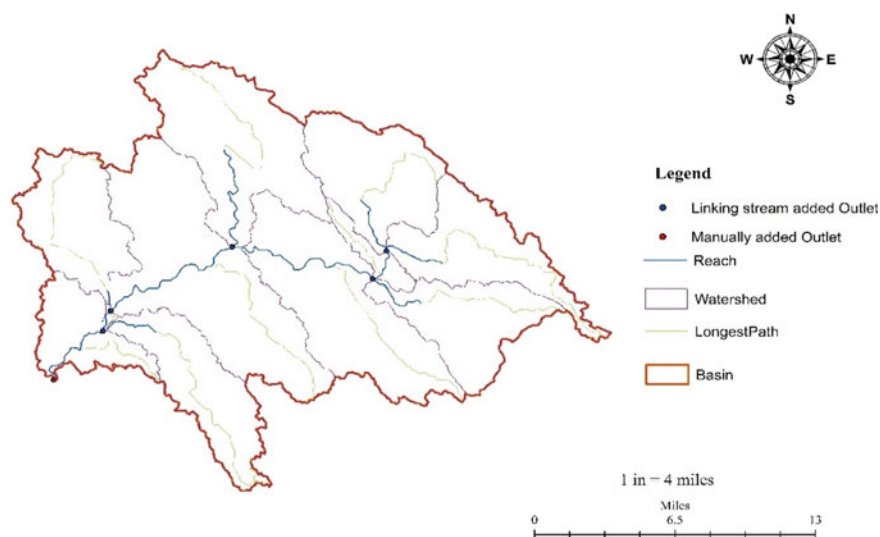
where NSE is the Nash–Sutcliffe model efficiency,  $i$  = time step,  $n$  = total number of simulated time steps,  $\text{obs}_i$  and  $\text{sim}_i$  are the observed and simulated values of streamflow, respectively, and  $\text{sim}_{\text{mean}}$  is the mean of the observation for the simulated time period [1].

$R^2$  and NSE values close to zero cannot be acceptable for model prediction. Generally,  $R^2$  and NSE values greater than 0.5 are considered acceptable. Those parameter values equal to one show a perfect match between simulated and observed data values. It also indicates that predicted variable can estimate the observed variable.

## 6 Results and Discussions

### 6.1 Watershed Delineation

The watershed was delineated by using the Digital Elevation Model; the model will find out the different possible streams that can form based on the relative elevations



**Fig. 5** Delineated watershed

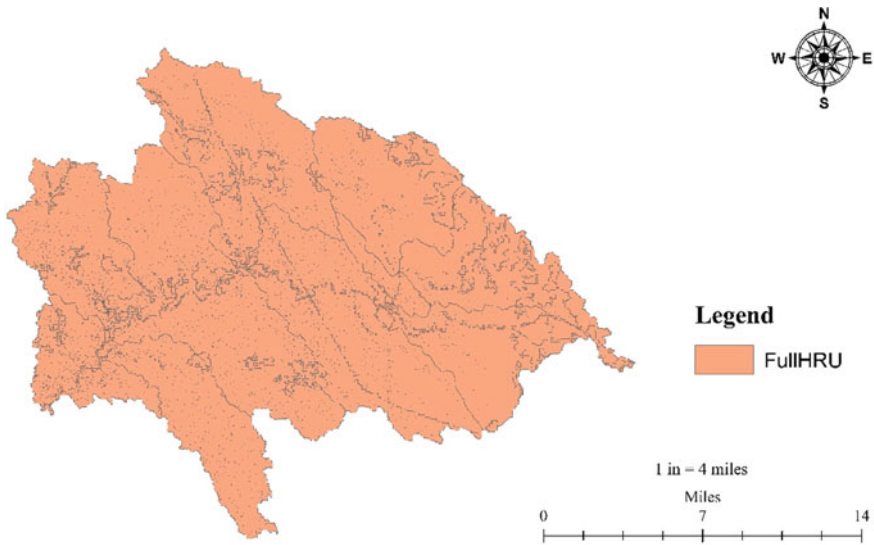
of various points in the study area. Once the streams were formed, one outlet was designated at the end of the stream networks, and then, the delineation process was carried out. The delineation is based on the topography of the area around each stream and reach of each stream. After the delineation process, the entire study area was divided into 11 sub-basins. The elevation of the entire sub-basin area is  $-3$  to  $1188$  m with a mean elevation of  $145.62$  m. These sub-basins were divided further in the HRU generation stage. The delineated watershed is shown in Fig. 5.

## 6.2 HRU (Hydrologic Response Unit) Generation

The large-scale diversity of the study area was illustrated by dividing the entire watershed into sub-basins and further sub-dividing it into series of hydrologic response units, which are unique soil-land use combinations. Land use data, soil class, and slope class were given as inputs for the generation of HRUs, and as a result, 97 HRUs were generated. All the components such as soil water content, surface runoff, lateral flow, and evapotranspiration were simulated for all the HRUs (Fig. 6).

## 6.3 Calibration and Validation of the Model

For calibrating the model, a preliminary sensitivity analysis based on the available climatic hydrologic data for the period 1997–2006 (10 years) was performed. The



**Fig. 6** HRUs

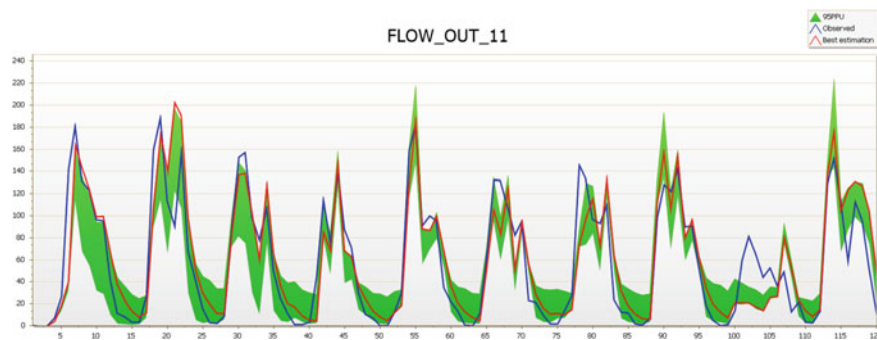
sensitivity analysis has been carried out for identifying the key parameters required for model calibration. There are more than 40 parameters influencing surface water in SWAT among which 9 parameters were shortlisted depending on the sensitivity of the parameters toward the objective of the study for model calibration [1]. In this study, global sensitivity analysis was performed using SWAT-CUP. SuFi2 algorithm in SWAT-CUP is used for calibration. Streamflow collected during 2007–2015 (9 years) for the Kidangoor station is used for validating the predictive capability of the SWAT model applied to Meenachil River Basin. In this study,  $R^2$  and NSE are considered as evaluation criteria. The outlet of the drainage area, i.e., Kidangoor gauging station, is used in calibration for streamflow.

The streamflow calibration process was completed by varying several SWAT hydrologic calibration parameters within their acceptable ranges (Table 3), to match the model predicted monthly streamflow time series with corresponding measured values.

The most sensitive parameter in the calibrated parameter is RCHRG\_DP. A larger  $p$ -factor (around 1) and a smaller  $r$ -factor (around 0) should be achieved to have a better calibration and uncertainty results. The model performance has been assessed by comparing observed versus simulated monthly flows during calibration as well validation periods. The calibration after 3 iterations gave a comparably good fitting for the simulated streamflow with respect to the observed streamflow. The SWAT model shows good performance in simulating streamflow in the Meenachil River. The 95PPU (95 Percentage Prediction Uncertainty)  $P$  factor 0.61 and  $R$  factor or thickness coefficient equal to 0.65 during the calibration. Figure 7 shows the 95PPU band obtained after uncertainty analysis during calibration period.

**Table 3** Sensitive parameters and fitted values after calibration using SuFi2

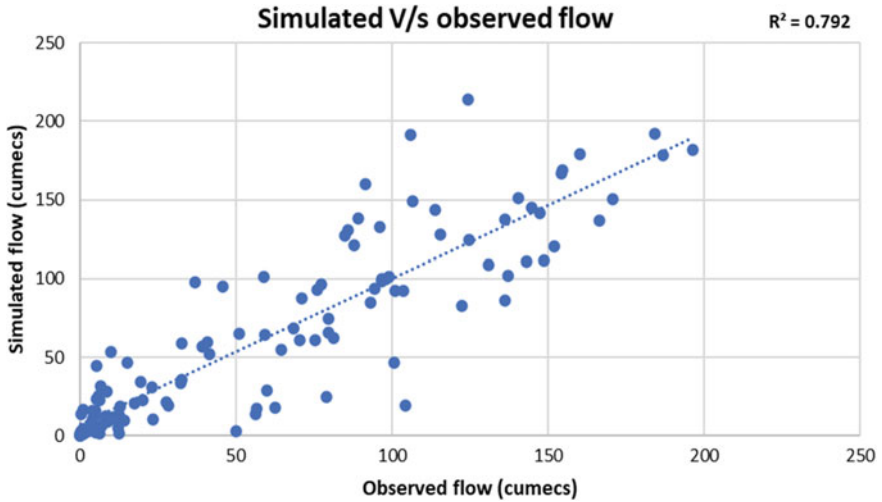
S. No.	Parameter name	Description	Fitted value	Minimum value	Maximum value
1	V__ALFA_BF.gw	Base flow alpha factor (days)	0.9	0	1
2	V__GW_DELAY.gw	Groundwater delay	50	0	500
3	R__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	300	0	5000
4	R__GW_REVAP.gw	Groundwater revap coefficient	0.1964	0.02	0.2
5	R__REVAPMN.gw	Threshold depth of water in the shallow aquifer required for revap to occur (mm)	130	0	500
6	R__RCHRG_DP.gw	Deep aquifer percolation fraction	0.94	0	1
7	R__ESCO. Bsn	Soil evaporation compensation factor (unit less)	0.06	0	1
8	R__CH_N2.rte	Manning's n for the main channels (unit less)	0.162	0	0.3
9	R__CH_K2.rte	Effective hydraulic conductivity in main channel alluvium (mm/h)	147	0	150



**Fig. 7** Hydrograph for simulated and observation flows with 95PPU band during calibration period

**Table 4** Statistical indicators

	Calibration	Validation	Remarks
$R^2$	0.79	0.82	Good
NSE	0.77	0.75	Good



**Fig. 8** Scatter plot for monthly simulated streamflow versus observed streamflow during calibration period (1997–2006)

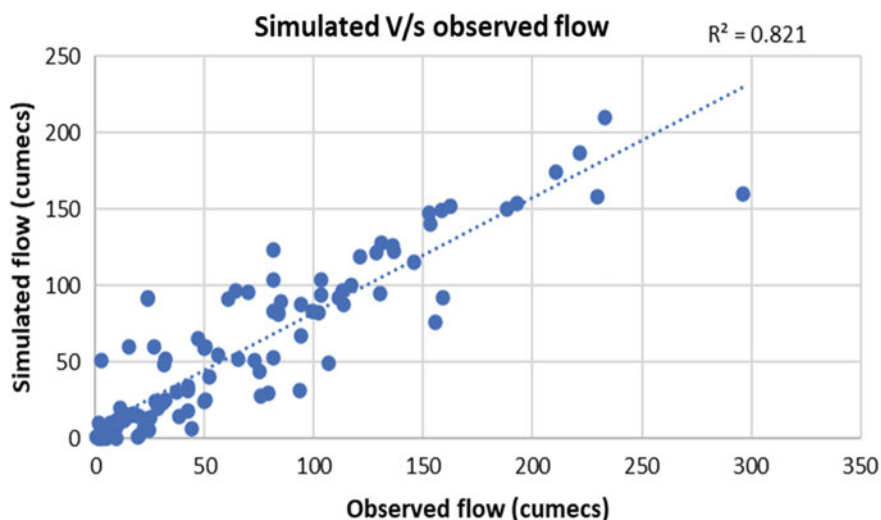
The measured and simulated monthly flow values matched well and showed a strong correlation with reasonable accuracy, as reflected by the strong  $R^2$  and NSE values (Table 4) for both monthly results. Figures 8 and 9 show the graphical representation of the calibration and validation results on monthly basis.

### 6.4 SWAT Model Results

#### Hydrology

Table 5 shows the average annual precipitation in the watershed and other important parameters like evaporation and transpiration, percolation to shallow aquifer, lateral flow, return flow, surface runoff, and recharge to deep aquifer; these parameters are important to understand the water availability throughout the watershed. Table 6 shows the water balance ratio of the model which reflects the correctness of the simulation.

From Table 7, potential evapotranspiration is the amount of evaporation that would occur if sufficient water source was available, and as expected, it is maximum in the month of March because high solar insolation along with this low precipitation may create water scarce situation during this month.



**Fig. 9** Scatter plot for monthly simulated streamflow versus observed streamflow during validation period (2007–2015)

**Table 5** Model check details

Parameter	Value (mm H <sub>2</sub> O)
Precipitation	3364.5
Evaporation and transpiration	699.4
Percolation to shallow aquifer	1487.06
Return flow	1383.34
Lateral flow	153.3
Surface runoff	1017.46
Recharge to deep aquifer	74.35

**Table 6** Water balance ratio details

Ratios	Value
Streamflow/precipitation	0.76
Baseflow/total flow	0.6
Surface runoff/total flow	0.4
Percolation/precipitation	0.44
Deep recharge/precipitation	0.02
ET/precipitation	0.21

**Table 7** Average monthly basin values

Month	Rain (mm)	SURF Q (mm)	LAT Q (mm)	Water yield (mm)	ET (mm)	Sed. yield (mm)	PET (mm)
1	9.62	0.21	1.65	76.91	24.01	0.03	127.28
2	28.18	1.50	0.93	30.43	42.33	0.61	122.75
3	64.34	1.87	1.45	12.22	71.15	0.03	175.41
4	170.94	12.15	4.44	24.04	73.90	0.07	113.77
5	287.94	86.76	8.46	116.35	79.57	0.64	118.92
6	623.59	230.56	20.07	329.78	68.89	6.47	89.81
7	652.04	230.65	29.57	453.80	69.75	13.63	87.33
8	496.75	166.87	26.48	445.94	68.50	16.92	92.59
9	368.13	110.27	20.21	366.37	58.61	20.39	91.60
10	396.87	117.19	19.11	355.06	55.25	28.02	77.45
11	207.62	49.73	14.72	256.22	50.35	17.20	86.16
12	58.22	9.68	6.20	159.70	36.76	4.27	109.44

High precipitation was observed in the month of July due to the effect of monsoon. The river basin experiences southwest monsoon starting from June and lasts till August. The northeast monsoon starts from October to the end of November [1]. Heavy precipitation during monsoon rain events leads to transport of pollutants to the river. The study area consists of 3 soil class which are sandy clay loam 46.007%, clay loam 53.389%, and sandy loam 0.004%. The study area is dominated by lateritic soils (clay). During high intensity rain in the monsoon months, the soil column gets saturated and the contact zone between the hard rock and the over burden is liquefied, resulting in soil slip.

### Nitrogen Cycle

Figure 10 shows the nitrogen cycle in the river basin. A high amount of fertilizer application was found. There was an increase in nitrogen (N) pollution of surface water. The application of nitrogenous fertilizers and straw decaying could be a possible source. Drainage from manure storage sites, livestock husbandry operations, and drainage from landfill sites are major causes of nitrogen pollution [13]. These point sources severely affect the quality of stream water. This causes eutrophication in the Meenachil River. The increased amount of  $\text{NO}_3$  concentration is an indication of anthropogenic pollution in the study area. It is mainly due to influences of poor sanitary conditions and over usage of higher fertilizers for higher crop yields in the study area. The  $\text{NO}_3$  originates from ammonium and  $\text{NO}_3$  fertilizers and aerobic decomposition of organic matter in the soils. Sewages generated from domestic and industrial activities and septic tanks are also remote sources of  $\text{NO}_3$  in the area. Controlled application of chemical fertilizers can reduce the nitrate loadings at the watershed outlet without affecting crop yield.



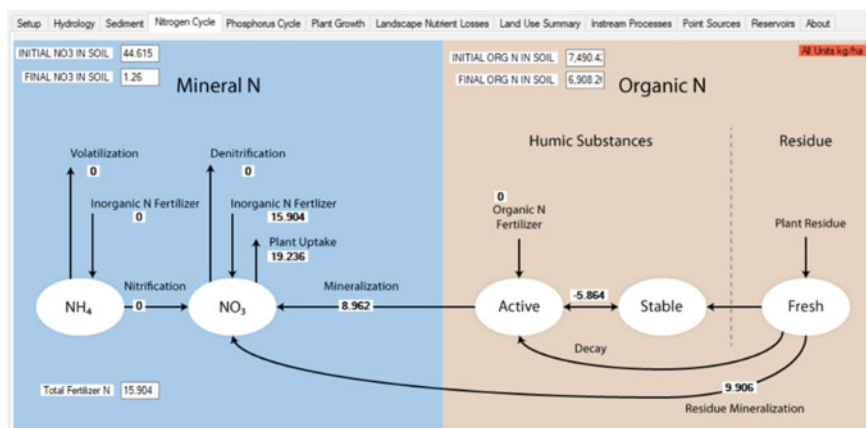


Fig. 10 Nitrogen cycle simulated in SWAT

### Landscape Nutrient Losses

The loss of nutrients and sediment from land originates from both diffuse, i.e., non-point sources (fertilizers, agricultural land) and point sources (industrial plants/factories, hospitals). Source type, emissions, and transport processes will determine the overall nutrient loss to stream. Generally, river basins, which have abundance of agricultural activities, have a major role in contribution of N and P into streams. Significant rise of phosphorous simulated (2.861 kg/ha) suggests the contribution of leachate from widespread rubber plantations in the upland catchment area. Phosphorus recovery from wastewaters and its reuse for agricultural purposes could bring practical solutions for both the intrusion of phosphate ores and the reduction in P-polluted water bodies.

Rubber trees are extensively cultivated in vast areas in the entire river basin (88.55%–720.15 km<sup>2</sup>) shown in Table 8. Crops like spices, paddies, etc., are also another agricultural land use in the basin area. The water body is polluted from the nearby paddy field, coconut, and oil palm plantations. As the percentage area under rubber plantation increases, the surface runoff decreases in the river basin. From Table 8, it is clear that more water is lost by evapotranspiration from the rubber plantation compared to other crop-cultivated area. This is maximum in the month of March due to high solar insolation along with low rainfall which may create water scarce situation in this month. Rubber is planted after removal of traditional crops or vegetations and building terraces. Due to the removal of top soils, the subsurface soils are exposed, which absorb water poorly. This can lead to accelerated soil erosion, disruption of natural streamflow, elevated stream sediments, and greater risk of landslides. Due to complete coverage, penetration of sunlight is restricted under canopy rubber plantation. This may affect water quality of the rivers flowing under rubber plantation for a long stretch.

**Table 8** Land use summary

LULC	AREA (km <sup>2</sup> )	PREC (mm)	SURFQ (mm)	GWQ (mm)	ET (mm)	SED (mm)	NO <sub>3</sub> (kg/h)	ORGN (kg/h)
Grasses	4.53	3215.65	1104.59	1206.04	801.04	15.66	3.83	22.40
Plantation (rubber)	720.15	3363.88	1019.74	1530.80	701.85	89.15	0.52	29.73
Shrubland	34.9	3388.58	952.30	1682.06	650.48	487.80	0.26	20.00
Mixed forests	11.14	3388.58	1034.86	1607.87	652.80	191.62	0.31	19.18
Water	0.06	3215.65	0.00	0.00	1126.45	0.00	0.00	0.00

## 7 Conclusion

SWAT2012 model was used to simulate streamflow in Meenachil River Basin of Kerala State, India. SWAT model was successfully calibrated and validated using SuFi2 algorithm in SWAT-CUP. The model performance evaluation was conducted with the prescribed statistical coefficients. A decent correlation was obtained agreement between the measured and predicted values on a monthly scale, as indicated by statistical parameters such as  $R^2$  and NSE. This good performance of the model makes it feasible for predicting streamflow in Meenachil River Basin. The calibrated model was used to study the effects of landscape, climate condition, and fertilizer application on sediment and nutrient loadings. With a monthly time step, this study has provided knowledge and insights into the availability of water at a sub-basin level, which helps to locate regions where a detailed analysis may be necessary. SWAT is used to simulate the nutrient cycle and provide useful insight into its application on similarly impacted agricultural watershed in central Kerala. The application of fertilizers in agricultural land, the drainage from composting sites and landfills, and animal husbandry operations have led to the presence of excess nitrogen and phosphorus in the water bodies. This in turn degrades the water quality, and the excess nutrients lead to increased algal growth. This phenomenon known as eutrophication affects the aquatic biota and eventually renders the water source unusable. From the study area, it was observed that there is a lack of awareness among the agricultural community regarding the environmental implications of the excessive use of chemical fertilizers and pesticides. From various studies, it is clear that the non-sanitary latrines, open defecation, poor drainage facilities, water-logging environment, and unethical dumping of domestic wastes have led to the deterioration of water quality in the study area. Consequently, the river is subjected to natural contamination by human activities. Hence, a general change in land use pattern, the reduced cultivation of rubber plants to reduce surface runoff and erosion, regular monitoring, removal of macrophytes in downstream, and an increased awareness among the community would help in implementing a good management strategy for reviving and protecting the water quality of Meenachil River and its tributaries.

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