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Calibration and validation of soil water assessment tool for Poondi Micro-Watershed

P. Eshanthini[a,*], S. Nandhakumar[b], T.R. Praveenkumar[c]

[a]*Department of Civil Engineering, Sathyabama Institute of Science and Technology, Chennai-600 119, India, email: eshaindia1@gmail.com (P. Eshanthini)*
[b]*Department of Applied Geology, University of Madras, Chennai-600 025, India, email: nandhu26@gmail.com (S. Nandhakumar)*
[c]*Department of Construction Technology and Management, Wollega University, Ethiopia, email: pravirami@gmail.com (T.R. Praveenkumar)*

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ABSTRACT

The sustainable management of watershed requires an accurate estimate of different hydrological parameter affecting the watershed. Surface runoff is an essential feature of watershed's hydrological process. The evaluation runoff volume of a watershed can be helpful for analyzing the flood risk and efficient design of hydraulic structures. The present study focus on modeling of rainfall runoff using ArcSWAT model where soil water assessment tool (SWAT) model was incorporate into ArcGIS software for Poondi Micro-Watershed, Thiruvallur, Tamil Nadu. The validation and calibration and of ArcSWAT version was done with SUFI-2 within SWAT-CUP for every month time periodic. And the calibration in the model was carried out during the years 2007 to 2014 and validated for the period of 2015–2018. The Nash–Sutcliffe value (NS) and determination in the co-efficient (R^2) are used to analyze in the correlation between the design model calibration and validation and it shows significant values greater than 0.70 in both the cases. Overall the performance the SWAT model was good and can be used for simulation of runoff.

Keywords: ArcSWAT software; Calibration; SWAT-CUP software; Runoff; Validation.

1. Introduction

Water is very important resource, which was utilized by human being, animal, plants and also used for agriculture. Runoff can be described as the part of hydrological cycle that water get flows over land as surface water or stream instead of water gets absorbed into groundwater or evaporated due to temperature. GIS is an important asset for water resource engineers and policy makers to prepare different watershed maps and graphs for efficient watershed management [1,2]. The hardware and software components of GIS permit to capture, store and analyze the data of watershed. In recent years the spatial data technologies like remote sensing and GIS were widely used [3]. Rainfall runoff affects human lives directly. The various issues involved in traditional method of managing water resource, environment and processing the data of vast area was overcome by the GIS tool [4]. The runoff water proves to be an important source for agriculture, industries and urban water use. It is very complicate to understand the relationship between rainfall runoff processes. The proper planning and management of water resource require an accurate estimation of runoff volume of a watershed. But due to unavailability of data there is always a problem in runoff estimation [5]. The SCS curve number method is the simple and globally practiced numerical model for rainfall

* Corresponding author.

runoff estimation, which integrate different physiographic characteristic in the watersheds like topography, land-use and soil for the simulation of runoff [6]. Hydrological modeling providing an efficient tool to estimate the runoff based on catchment characteristics and climate change [7]. It was categorized into deterministic, stochastic, physical, lumped or distributed and land surface models based on the characteristics of the runoff model. The various physical models are CEQUEAU, HYDROTEL, IHDM, MIKE-SHE, SHE, SLURP, soil water assessment tool (SWAT), SWMM, TOPMODEL and WATELOOD. The various hydrological parameters such as precipitation, snow melt, soil moisture dynamics, runoff, evapotranspiration and infiltration are incorporate into distributed hydrological model [8]. A distributed hydrological model can also be used in quantify the effect of land management practices on runoff [9]. The ArcCN-Runoff and ArcSWAT both using the data from the Geographical Information Technology System (GIS) and also through the remote sensing for analyzing the maps and graphs generated from the model. Combining out the GIS and remote sensing will enhance the rainfall and runoff prediction [10]. The SWAT model is used-out to investigate the effect in land use practice on the yield of sediment, and agricultural-chemical effect in the water quality [11,12]. The runoff for the Xitiaoxi-basin in the eastern side of China was simulated using hydrological models, Hydrological Simulation Program-FORTRAN and SWAT. This model was used to predict how land use would affect runoff and an accidental analysis of uncertainty judge method (SUFI-2) was used to determine the parametric uncertainty [13].

The software also used to detail the various components such as weather surface flow, transmission losses, reservoir and lake storages, crop growth and irrigation, evapotranspiration, percolation and water transfer. ArcSWAT is suitable to simulate the hydrological model for daily and monthly simulation [14,15]. In water resource management investigations careful uncertainty prediction and calibration hydrological models are required [16]. The base flow of groundwater re-evaporation, surface run-off and deep out aquifer percolation are all modeled in SWAT using a collection of empirical equations [17]. In order to develop a natural watershed system, the SWAT model integrates the steam network, categories out the types of soil, and divides the land covers into multiple groups using out the principles of a hydrological units of response. Interpretation of results of the complicated watershed models takes a lot of time and effort. It also requires more effort and intensive labor to convert model inputs into the correct format and files [18]. In the Onkaparinga catchment in Australia, a comparison of single site calibration and various site calibrations in the SWAT model for total nitrogen, total phosphorus and suspended solids are found out in a one single site calibration model produced out for the better result. For a flow simulation and nutrient loading, the SWAT model is been proved out to be a better toolset in the catchment of arid [19]. Through trial and error, multi-site and multi-variable methods are to calibrate and verify SWAT are been used out. The model was used to calibrate not only internal hydrological processes, but also a number of sub-catchments [20]. GIS and remote sensing enhance a process of a data entry, as well as the treatment and crossing of various layers of data watershed models. The SWAT model aids in the long-term management of the Kalya river basin by providing an accurate evaluation of parameters needed for dam construction planning and future flood risk assessment [21]. LANDSAT provides out an indirect soil- moisture estimation in 2016 Ilmenau river basin Northern Germany, the SWAT model was used to study the spatial and temporal pattern of daily soil moisture simulated out for the upper 30 cm of the profile soil [22]. The SWAT model is used out to investigate the combined and distinct effect of climate and land use change on run-off in the Baltic Sea area. The study's findings show that the relationship between annual stream flow and change in forest cover was linear and significant [23].

Temperature changes have a big impact on evapotranspiration, humidity, rainfall pattern and wind, as well as formation of ice and melting. The most important parameters for watershed modeling are air temperature and precipitation. The successfulness of the hydrological model was evaluated based on these two factors [24,25]. The impact of different weather information systems like National Climatic Centre (NCDC), the parameter-elevation Regression in Independent slope model (PRISM) and Next-Generation Weather Radar (NEXRAAD) in the base of stream-flow was calculated using out SWAT models. The comparison of weather information system shows that the PRISM information system proved better statistical performance over other two models. The gridded weather dataset provide improved stream flow at daily, monthly and yearly scales. The SWAT model was successfully used for estimation of flow in arid and semiarid catchments in South Africa [26]. For regionalization process of the catchment the factors which they have considered are point and non-point sources of sediment, nitrogen, pollution and phosphorus loading. The sensitivity, validation and calibration in the models are done with specialized computer program called SWAT-CUP (SUFI-2). The sensitive parameter for calibration was taken from SWAT-CUP sensitive analysis and the prioritization of the sensitive parameter a one parameter at a time procedure was followed. The p value and t value are used for global sensitivity and prioritization [27]. The present study focused on calibrate and validate the ArcSWAT model for Poondi Micro-Watershed out in-order to predict the run-off in an watershed.

1.1. Study region

Poondi Micro-Watershed is a sub watershed of Kosasthalaiyar river basin located in Tiruvallur district and the watershed number is 4C2C4b1. The study area lies between longitude 79°42′ to 79°54′36″ and latitude13°1′40.8″ to 13°12′50.4″. The Poondi Micro-Watershed has total catchment area of 528 km^2 (Fig. 1). Poondi reservoir in this watershed gives necessary water source to the Chennai city which is lying 60 km away from the Poondi region. The watershed have receives heavy rainfall in the north-east monsoon of the years and has attain huge inflow of water during this respective monsoon season. The watershed receiving huge flow of water from Kosathalaiyar River basin and Krishna River basin located in Andhra Pradesh. The elevation of the Poondi Micro-Watershed is 76 m and annual mean rainfall for the region is 604 mm.

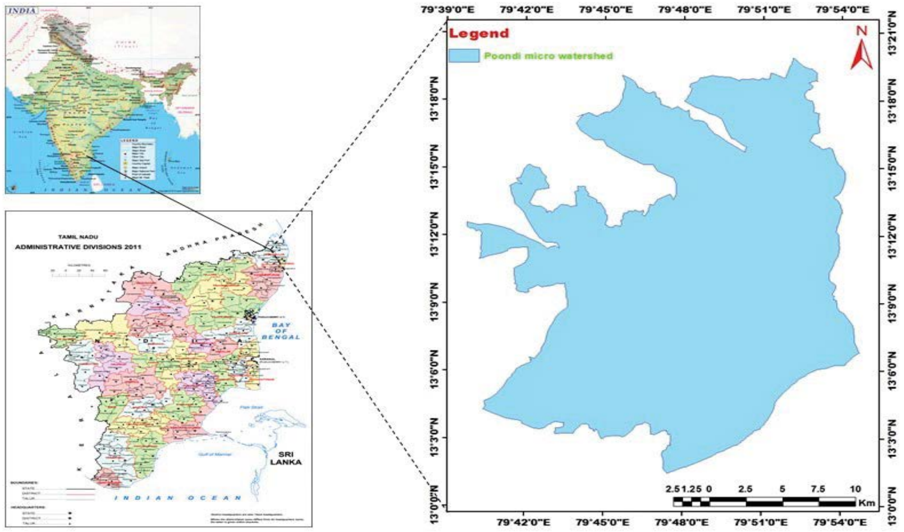

Fig. 1. Location of Poondi Micro-Watershed.

2. Methods and data

2.1. Data input

Basic Input file in the SWAT Models are includes the digital elevation model (DEM), land cover map and land use, and soil map. The digital elevation models are downloaded in 30m resolution from the Shuttle-Radar Topography Mission (SRTM-open topography webpage). The other basic weather data required to prepare rainfall-runoff model such as solar radiation, wind speed, maximum temperature, precipitation, relative humidity, minimum temperature and stream flow data for 12 y from 2007 to 2018 was collected from Institute of water studies Taramani, public works department in Poondi and Thiruvallur. The SWAT WGEN table values are calculated from SWAT WGEN statistics option from weather database platform.

2.2. SWAT model

The semi distributed SWAT model can be used to calculate the water quality status, sediment yield and runoff volume of the watershed due to the change in land management practices. The integrated ArcSWAT in ARCGIS prove to be suitable tools to calculate different hydro-logical parameter of the watershed. The hydrological response unit (HRU) is used to represent heterogeneity in watershed [28]. The different watershed characteristics used in HRU analysis are slope map, soil map and land use/Landover map. This model also requires weather data for prediction of surface runoff. The governing equation of SWAT model is [29].

$$\mathrm{SW}_t = \mathrm{SW}_0 + \sum_{i=1}^{t}\left(R_{\mathrm{day}} - Q_{\mathrm{surf}} - E_a - w_{\mathrm{seep}} - Q_{\mathrm{gw}}\right) \quad (1)$$

where SW_t – depth of final soil water (mm; SW_0 *i*-depth of initial soil water (mm); t – time (d); R_{day} – rainfall on *i*-th day (mm); Q_{surf} – depth of runoff on *i*-th *d* (mm); E_a – evapotranspiration of water on *i*-th day (mm); w_{seep} – seepage of water into Vadose Zone (mm); Q_{gw} – groundwater runoff on *i*-th *d* (mm).

2.3. SWAT – CUP model

The hydrological modeling is subjected to large number of uncertainties, in order define and quantify these uncertainties researchers has developed many uncertainty investigation approach for different watershed models. The various calibration programs such as SUFI-2, Parasol, Glue and MCMC incorporated in SWAT-CUP to meet different modeling objectives [30]. In this study the uncertainty caused due to different input and output parameters like rainfall, type of soil and different land use parameters have been calculated using SUFI-2 combined with SWAT. The uncertainty in simulation was evaluated by *p* factor for 95% of predictions are uncertainty. The soundness of calibration was also quantified by the ratio of an basic thickness of the 95 PPU bands out to standard deviation which acts as observed data called as *r* factor. On an average thickness in the 95 PPU bands $\bar{r}$ and the *r*-factor are to calculated by an equation.

$$\bar{r} = \frac{1}{n}\sum_{t_i}^{n}\left(y^M_{t_i,97.5\%} - y^M_{t_i,2.5\%}\right) \quad (2)$$

$$r - \text{factor} = \frac{p - \text{factor}}{\sigma_{\text{obs}}} \quad (3)$$

where $y^M_{t_i,97.5\%}$ and $y^M_{t_i,2.5\%}$ represent lower and upper boundaries of 95 PPU and σ_{obs} represents SD of observed data.

The efficiency of an model was evaluated using statistical values such as R^2 and Nash–Sutcliffe (NASH) co-efficient calculated by SUFI-2 software package of SWAT-CUP model between the observed and simulated runoff data [31,32]. The NASH co-efficient is given by.

$$\text{NASH} = 1 - \frac{\sum_{i=1}^{n}\left(Y_i^{\text{obs}} - Y_i^{\text{sim}}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{\text{obs}} - Y^{\text{mean}}\right)^2} \quad (4)$$

2.4. Digital-elevation models

The digital elevation model map is been prepared out for the study area from SRTM data's considering of a 30 m spatial resolution. The SRTM data was downloaded for zone WGS-1984-UTM-Zone 44N in a coordinate system which is been projected out. Fig. 2 shows DEM map of Poondi Micro-Watershed. The maximum elevation in the watershed is 343 m and lowest is 28 m.

2.5. Soil map

The type of soil present in the watershed is one of the important factors which will determine the runoff volume, Infiltration capacity and moisture hold stability in the soil is based-on its type. The antecedent moisture holding capacities of the soil based on its moisture holding capacity and intensity of rainfall. The physical characteristic of the in the watershed is sand, sandy loam, silty sand and clayey loam. The soil is grouped into four categories as alfisols, entisols, inceptisols and reserve forest. Fig. 3 shows soil map of Poondi Micro-Watershed.

2.6. Landuse/Landcover map

The landuse describes the how the land area is utilized by human activity and economic activity.

The landsat image for the year 2018 was downloaded from the USGS website. The supervised classification method was used to find the landuse practices in the area. The map was prepared using ArcGIS version 10.3. The major land use classification was taken for concern such as waterbody, agriculture lands, urban area, buildup villages, barren land and forest. Fig. 4 shows the Landuse/Landcover map of Poondi Micro-Watershed. The major group of soil was under agriculture and buildup villages.

2.7. Basin delineation

The runoff estimation in ArcSWAT starts with ArcSWAT model setup. In this process a separate folder was created to start the new project. The basin delineation in ArcSWAT

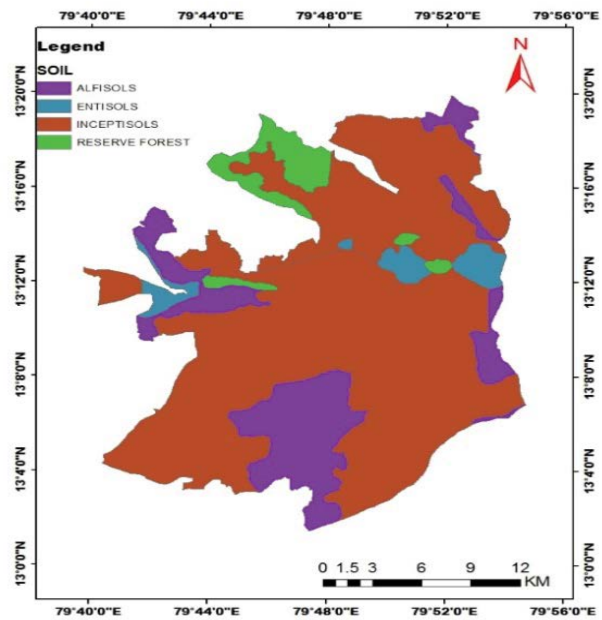

Fig. 3. Soil map.

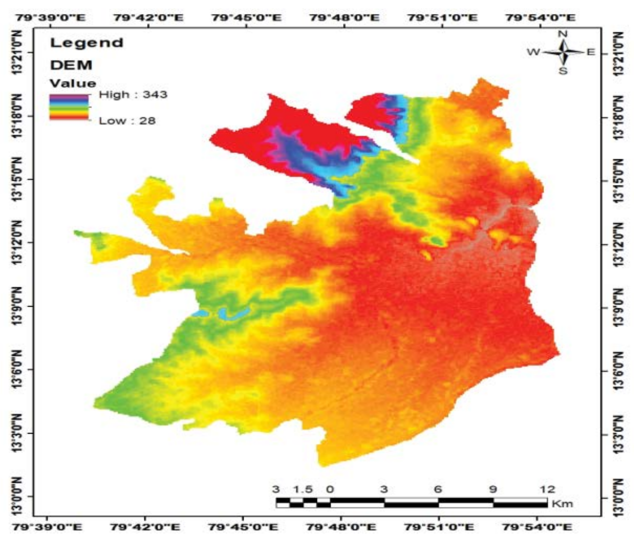

Fig. 2. Digital elevation model.

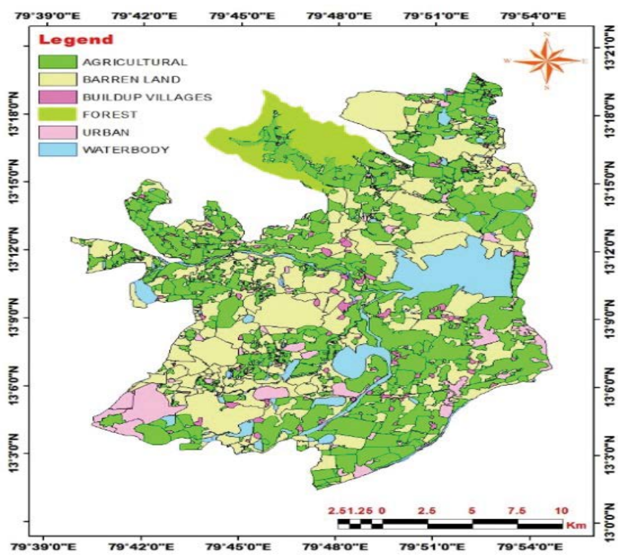

Fig. 4. Landusetmap.

needs a DEM of the study area is an input file. From the mask command in the ArcSWAT model the required area from the DEM data has been extracted. In basin delineation using DEM the drainage pattern of the watershed has been created using automatic delineation in ArcSWAT. The drainage pattern gives and the stream networks in the watershed. To define the position of stream network the flow path was identified by filling the non-drainage zones of the watershed and the digitized stream networks are superimposed into the DEM. The ArcSWAT requires minimum and maximum drainage area for delineation. In general if the drainage area is less many accurate will be the drainage pattern. The watershed delineation also divides the given watershed into multiple – numbers of various sub-basins. After deciding multiple of sub-basins in outlet of the watershed also has been selected. If any reservoir present in the watershed that also can be selected while delineating the watershed. Fig. 5 shows delineation of Poondi Micro-Watershed. There are four sub basins are derived from the watershed during the delineation process and the delineated area was 395.987 km².

2.8. HRU definition

In HRU definition the different land area in the watershed was divided into hydrological response units. Individual fields distributed around a sub basin with a particular land use, management, and soils are grouped together as HRUs. It is one of the important factor which will affect stream flow. The HRU analysis in the SWAT model grouping the unique landuse management and soil group into a single HRU. In HRU analysis the soil map and land use map prepared in ArcGIS where given as the input file. The soil map and land use map were inserted into the SWAT model by creating the look-up tables manfully. Once the look-up table was created the reclassification of soil type and land use percentage have been done by the model for Poondi Micro-Watershed. Table 1 shows the percentage of different land use management practices.

Various slope classes can be chosen after classification in the field of land use and soil maps in the watersheds was done. The watershed was classified into five types as 0%–10%, 10–20%, 20–30%, 30–50% and 50–99.99, the number of slope classification is based on the convenience.

The more reliable estimate of stream flow was given by following threshold combination of scenarios of 5% land-uses, 10% soils and 5% slope. In HRU analysis divides out the whole watershed in to 23 HRU's and 4 sub-basins.

2.9. Weather data

The daily weather data of Poondi Micro-Watershed was collected for 12 y from 2007 to 2018 was collected. The various weather data which needed to run the SWAT model are rainfall, humidity, temperature, wind speed and solar energy. The data was prepared in suitable format to insert WGEN database platform. The weather data has made in excel sheet and this data are converted in to CSV (comma delimited) file format for SWAT Weather Database. WGEN database platform was introduced in a way get the input file for SWAT software. The validation of the models and calibration was done with SWAT-CUP model using

Table 1
The percentage of land use area are obtained after delineation

Land use code	Description	Area (km²)	Area in percentage
WATR	Water body	39.24	9.91
AGRR	Agriculture land	151.11	38.16
URHD	Urban area	19.37	4.89
URLD	Build up villages	9.11	2.30
BARR	Barren land	157.68	39.82
FRST	Forest-mixed	19.48	4.92
	Total	395.98	100

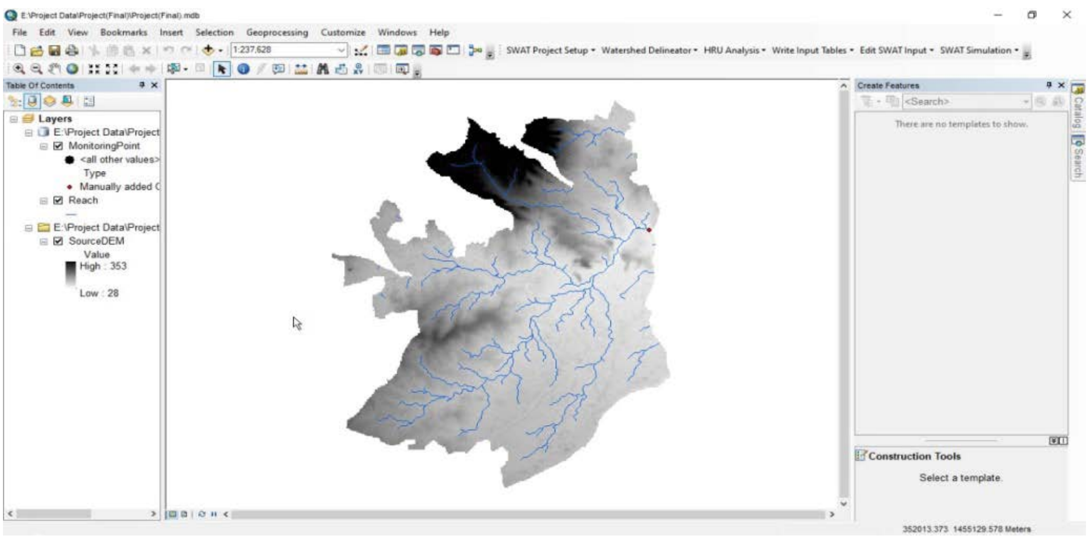

Fig. 5. Watershed delineation.

calibration and uncertainty programs after exporting the input data into the model. Fig. 6 shows weather generation database for SWAT model.

3. Results and discussion

From the parameter estimation process the model sensitivity parameters were identified. Sensitive parameter are identified for the study area are SCS runoff curve number in the for CN II, on base-flow of alpha factor, the groundwater delay time, And threshold depth in the water shallow-aquifer for return flows to occur, groundwater "revap" co-efficient, Availability of water capacity in the soil layer, saturated hydraulic conductivity, and moist bulk density, soils evaporation compensation factor (ESCO.hru), rainfall adjustment (RFINC.sub). These factors are considered as model sensitive parameters.

3.1. Model validation and calibration

Model calibrations is a step of process in altering out the model input parameter in order to obtain out the model outputs values that are consistent with the data collected in the research area. The model input parameter can be easily adjusted out manually or mechanically. The models validation has to be done after calibration of the model. In model validation the output in the calibrated model is been checked with the observed data's in field for several years. The validation process predicts the accuracy of the model. The model calibration for stream-flow is carried out using an SWAT-CUP software. This research SWAT-CUP is used to calibrating out the stream-flow. The monthly discharge data of watershed was collected from the Poondi rain gauge station for the years 2007 to 2018.This data is from 2009–2018 is used for model calibration and validation. The data from 2007 to 2008 was used warm up the model.

3.2. Monthly calibration and validation

The comparison of calibrated and validated values shows the effectiveness of the model in order to calculate the run-off. The monthly calibration in the model was carried for 8 y from 2006 to 2014 and monthly validation was done for 4 y from 2015 to 2018. In calibration process the model was trained for 2 y hence the model simulations has been carried-out for almost 12 y from 2009 to 2018. Figs. 7 and 8 show the hydrograph of watershed during monthly calibration and validation of the watershed. The highest rainfall in this study-area is received in November, 2015. The effectiveness of the model was analyzed based on average coefficient of determination (R^2), Nash–Sutcliffe efficiency (NSE), and average RSR. The average RSR value of monthly calibration was 0.49. The average Nash-Sutcliffe efficiency value is greater than 0.75 for both monthly calibration and validation, the co-efficient of determination values for both calibration and validation is greater than 0.80. The statistical values of the model after calibration and validation shows out the SWAT model can be used for the Poondi Micro-Watershed for hydrological studies.

3.3. Uncertainty analysis and discussion

The SWAT-CUP software is used to be calibrated and validate the SWAT model for Poondi Micro-Watershed. The similarity in-between is observed runoff volume and simulate runoff volume was compared in terms of statistical values like Nash–Sutcliffe efficiency, co-efficient of determination and RMSE observation standard deviation ratio which are calculated by SUFI2 algorithm of SWAT-CUP software during monthly calibration and validation process.

The statistical values obtained during calibration are not in statistical performance rating. By using trial and error method the parameters values are changed and statistical performance rating are obtained with the

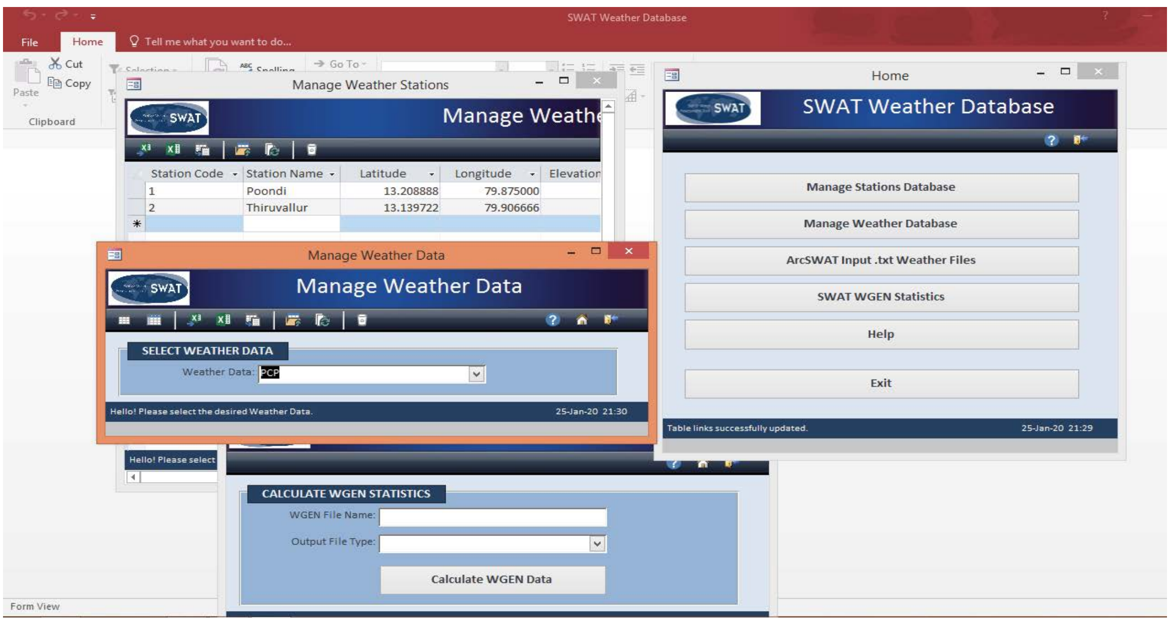

Fig. 6. Weather generation data.

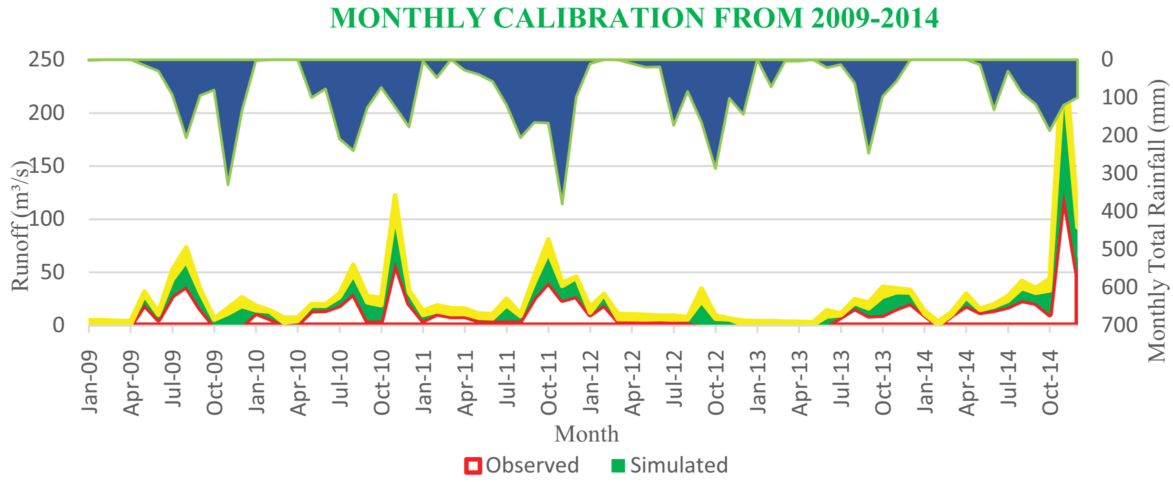

Fig. 7. Monthly calibration of SWAT model.

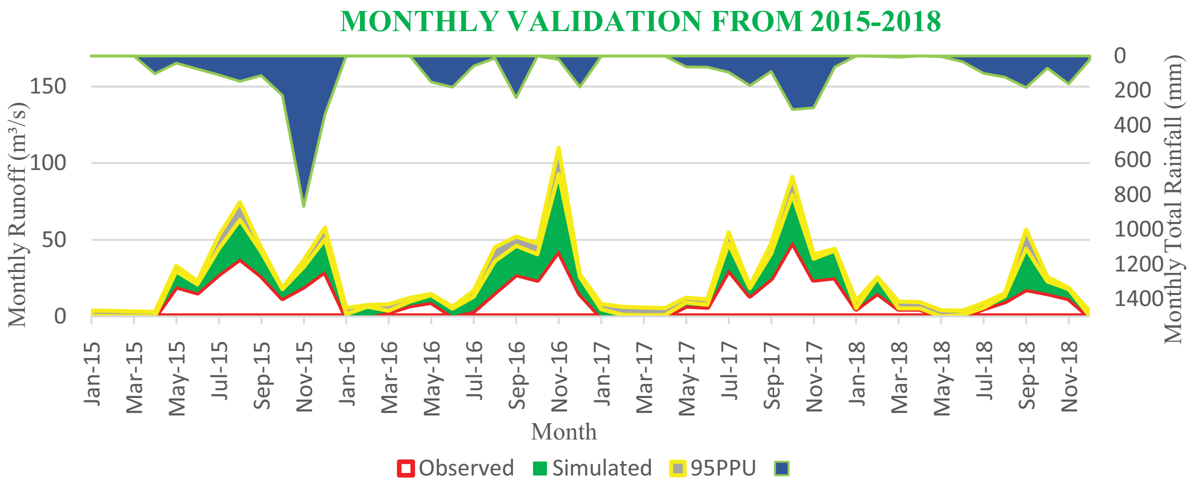

Fig. 8. Monthly calibration and validation of the SWAT model.

suitable limit. The statistical parameter performance rating is given in Table 2. The statistical parameter has been updated by getting new statistical parameter value from the previous simulation of rainfall-runoff model of Poondi Micro-Watershed.

Table 3 contains the most sensitive parameters value, where noted from calibration process of rainfall-runoff model of Poondi Micro-Watershed. This sensitive parameter values are important to reduce the deviations in the flow graph between observed and simulated stream flow values.

4. Conclusion

The rainfall-runoff model was performed effectively, during the period of calibration and validation in Poondi Micro-Watershed. 10 y of stream flow data (2009–2018) was divided in to 4 y for validation and 6 y for calibration. The auto calibration is simulated for the period of 2009–2018 and validation was done for the period 2015–2018.

Table 2
Performance rating of statistical values

Performance rating	RSR	NSE
Very good	0 < RSR < 0.5	0.75 < NSE < 1
Good	0.5 < RSR ≤ 0.6	0.65 < NSE ≤ 0.75
Satisfactory	0.6 < RSR ≤ 0.7	0.5 < NSE ≤ 0.65
Unsatisfactory	RSR > 0.7	NSE < 0.5

In Poondi Micro-Watershed 40% of the area was covered with agricultural lands and the topography of the surface was mild slope and the percentage of forest area covered is less. If the runoff water was used in effective method, then it helps to increase the percentage of area covered for agriculture purpose.

The Nash–Sutcliffe efficiency (NSE) statistical value of the model after calibration and validation was 0.78. The coefficient of determination (R^2) values are 0.84 for

Table 3
Most sensitive parameters with calibrated values

Parameter	Description	Fitted value	Min. value	Max. value
CN2.mgt	Runoff curve number	55.09	35	98
ALPHA_BF.gw	Base flow alpha factor	0.85	0	1
GW_DELAY.gw	Groundwater delay time	60.5	0	500
GWQMN.gw	Threshold depth of water in the shallow aquifer for return flow to occur	695	0	5,000
GW_REVAP.gw	Groundwater "revap" coefficient	0.176	0.02	0.2
SOL_AWC.sol	Available water capacity of soil layer	0.161	0	1
SOL_BD.sol	Moist bulk density	1.141	0.9	2.5
SOL_K.sol	Saturated hydraulic conductivity	590	0	2,000
ESCO.hru	Soil evaporation compensation factor	0.633	0	1
RFINC.sub	Rainfall adjustment	44.10	0	100

calibration and 0.93 validation and RSR value for calibration was 0.47 and validation was 0.46, respectively. The statistical value shows that the precision of the model was good. The SWAT tool can be used as important software to integrate the basin management with water flow and gives better agricultural management and irrigation methods and it will helps to improve the socio-economical activity of the human beings.

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