

Simulation of Runoff for an Agricultural Watershed Using SWAT Model

Sowmiya S¹, Carolin Arul²

P.G. Student, Hydrology and Water Resources Engineering, Anna University, Chennai, Tamil Nadu, India¹

Associate Professor, Centre for Water Resources, Anna University, Chennai, Tamil Nadu, India²

ABSTRACT: Many environmental problems are caused by changes in aspects of the hydrological cycle. Hydrological conceptual modelling combine with field experiments can give us a better understanding of the components of the hydrological cycle from which one can develop appropriate management options. The estimation of runoff can be used to assess other impacts like erosion of earth surface, environment impacts, flooding, agricultural issues and so on. These impacts play a key role to design water resource structures for every civil engineer, so it is important to calculate the runoff exactly. The study area chosen is an agricultural watershed, simulation of runoff and study of water balance parameters mainly helps for the developing irrigation projects. In this study QSWAT, a QGIS interface for SWAT (Soil and Water Assessment Tool) was used for modelling the sub basin to estimate the runoff and other parameters. Data has been collected for the period of 2000-2014 and model has been calibrated and validated for 15 years of observed data using SUFI2 calibration technique. The performance evaluation of the model has been done with NSE (Nash Sutcliffe Efficiency) and R² (Coefficient of determination). The model performance co-efficients gives reasonably average results for both calibration and validation.

KEYWORDS: Runoff, SWAT, Simulation, Hydrological Cycle, Watershed

I. INTRODUCTION

Water is a very precious natural resource and at the same time very complex to manage. Therefore, this one line objective is a mammoth task if this very precious resource has to be managed judiciously. A watershed is a hydrologic unit which produces water as an end product by interaction of precipitation and the land surface. The quantity and quality of water produced by the watershed are an index of amount and intensity of precipitation and the nature of watershed management. As fresh water resources are increasingly strained by agricultural and industrial usage, water conservation has become more and more important. As water demand increases, issues on water availability and demand become critical. This makes the management of water resources (assessing, managing and planning of water resources for sustainable use) a complex task. It has become more critical in places where rainfall is very low and erratic.[6]. One such watershed is the Amaravathi, which is most predominant in agriculture and lies in the semiarid zone of Tamil Nadu. Apart from agriculture practices, mis-managed usage of water by industries and dependent communities results in huge loss of productive soil and water as runoff in this basin. Hydrological modelling of the basin to simulate the flow at various locations in the river where observations are being made so as to validate the model. Assessment of flow for all the watersheds using the modeling framework is very essential for taking up any development work. To harvest maximum total quantity of water throughout the year for irrigation and drinking purpose through source development, lifting water, boring of tube wells and by providing efficient distribution systems.

I.1. Study Area

Amaravathi is the major tributary of river cauvery in Tamilnadu, India. Throughout its course of 256 km it receives number of small streams. The study area upper Amaravathi region lies almost in the southwest of Amaravathi river basin and lies between the latitudes 10°06'51" N and 10°74'10" N and longitudes 77°03'24"E and 77°53'06" E, it is shown in Figure.1. The watershed area is of 2,498 sq.km. and almost half of the region is under forest cover. The southwest region is overlapped by western ghats mountain ranges with forest lands and predominant agricultural lands

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in north west region. The average annual rainfall varies from 700-900 mm. This area has four distinct seasons, Southwest monsoon from June to September, Northeast monsoon from October to December, winter season from January to February and summer from March to May. The highest monthly mean of daily maximum temperature is around 40.6°C in April and the lowest monthly mean of daily minimum temperature is 22.4°C during January. The maximum average wind speed is 32.6 kmph. in the month of June. The minimum average wind speed is 9.5 kmph. in November[6].

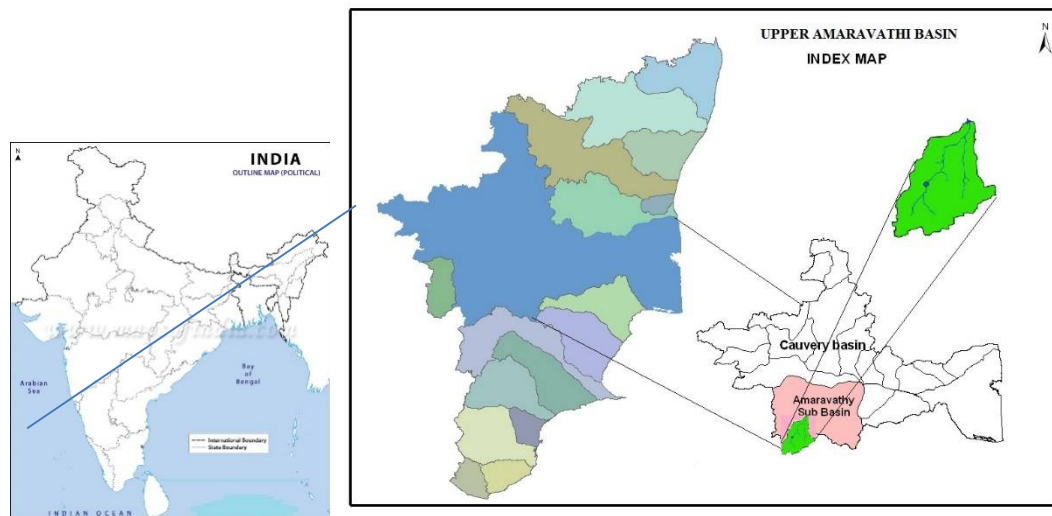


Fig. 1. Study Area, Upper Amaravathi River Basin, Tamil Nadu

I.2. QSWAT Model

SWAT (Soil and Water Assessment Tool), is a public domain model actively supported and developed by the United States department of Agriculture - Agriculture Research Services (USDA-ARS) and Agriculture Experiment Station in temple, TEXAS. QGIS which is integrated with SWAT, the model which was newly launched in 2015, has been used for the study. SWAT is a river basin scale model developed to quantify the impact of land management practices in large and complex watersheds. SWAT is a continuous time model that operates on a daily time step at basin scale. SWAT has wide range of applications ranging from prediction of long-term impacts in large basins and also timing of agricultural practices within a year, simulation at the basin scale water and nutrient cycles in landscapes whose dominant landuse is agriculture. In the SWAT model, simulation of the hydrology of a watershed can be separated into two major segments. The first segment is the land phase of the hydrologic cycle, it controls the amount of water, sediment, nutrient and pesticide loading to the main channel in each sub basin. The second segment is the routing phase of the hydrologic cycle which can be defined as the movement of water, nutrients and sediment through the channel network of the watershed to the outlet. Variable storage and Muskingum method can be used in SWAT to route the flow in channel network. The land phase of the hydrologic cycle as simulated by SWAT is based on the water balance equation (units in depth of water) as given in equation.1 below:

$$SW_t = SW_o - Q_{surf} - R_{day} - E_a - Q_{gw} - W_{seep} \quad \dots \dots \text{Equation.1}$$

where, SW_t is the final soil water content (mm), SW_o is the initial water content (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), Q_{gw} is the amount of return flow on day i (mm) and W_{seep} is the amount of water entering the vadose zone from the soil profile of day i (mm).

The data required for the model are Slope data, soil data, landuse data, precipitation and other weather data. Data about

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the weather parameters of the study area includes precipitation, temperature, average relative humidity, wind speed and solar radiation. A basic computational unit namely the Hydrologic Response Unit (HRU) is formed with same soil type, slope and landuse. The model features were daily time step term simulations, basins subdivided to account for differences in soils, landuse, crops, topography, weather etc.

Literature survey was undertaken to understand the concepts of rainfall runoff process, parameters influencing the water balance in a watershed, and conceptual models and its works. Few works are mentioned here, which includes Shivhare et.al.,[9] has modelled and estimated the surface runoff for Tapi subcatchment area in India using SWAT, Performance evaluation of the model has been explained. Adeniyi, et.al.,[2] has applied SWAT as a tool to estimate the water yield and water balance of a sub catchment in Nigeria.

II. METHODOLOGY

II.1. Database Development for the Study Area

Spatial attribute and dynamic data was collected for the Amaravathi sub-watershed area. Digital elevation model is one of the main input of SWAT. The Shuttle Radar Topography Mission (SRTM) data of 90m x 90m resolution and landuse map were obtained from the Institute of Remote sensing, Anna university, chennai. The DEM was created for the Amaravathi sub-watershed from the STRM data. Landuse map gives the details over the generation of land flow, soil water storage, water demand for irrigation etc. Landuse of various categories of the Watershed are given in the Figure 2. In QSWAT, various soil properties like soil texture, hydraulic conductivity, bulk density, water content are essential to make an input to the model. Soils with texture sandy/sandy loam is considered as class A (High infiltration rate and low runoff potential), with texture silt loam/loam as class B (Moderate infiltration rate), with texture sandy clay loam as class C (low infiltration rate), and with texture clay loam/clay/silty clay as class D (very slow infiltration rate and high runoff potential)[2]. The soil map of the study area collected from TNAU, Coimbatore is shown in Figure3(b).

Daily precipitation data collected from five rain gauge stations along with minimum and maximum temperature data, wind speed, solar radiation, and humidity were generated by the weather generator and used to run the model. Daily inflow and outflow of the reservoir measured using the gauge at Nallathangal Dam, Dharapuram, Tamil Nadu were also used as input data.

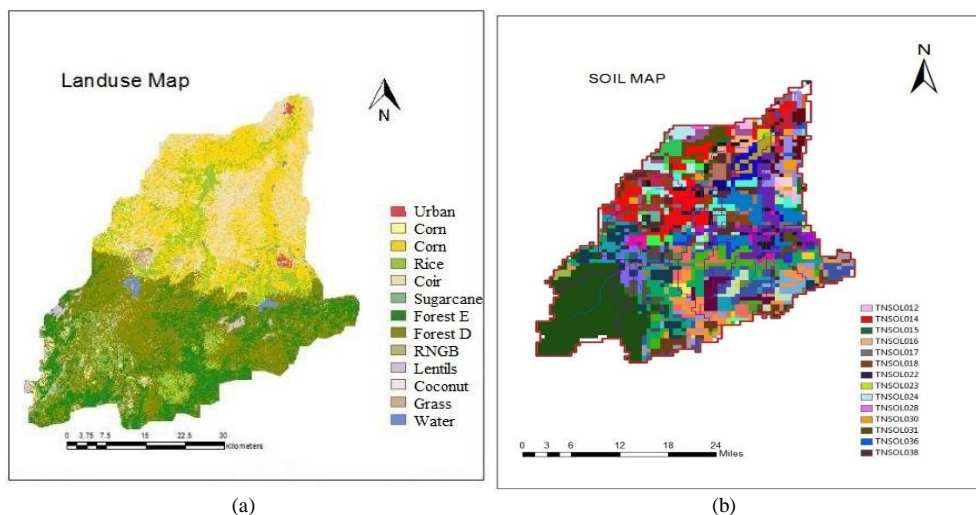


Fig. 2. (a) Landuse/Land cover Map (b) Soil Map of Amaravathi Sub basin

II.2. Model Setup

SWAT can be used to simulate a single watershed or a system of multiple hydrologically connected watersheds. QGIS Desktop allows the user to perform the full range of GIS tasks from geodatabase design and management to data

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editing, from map query to cartographic production and sophisticated geographic visualization and analysis. SWAT model executed with QGIS extension has been used to run the model.

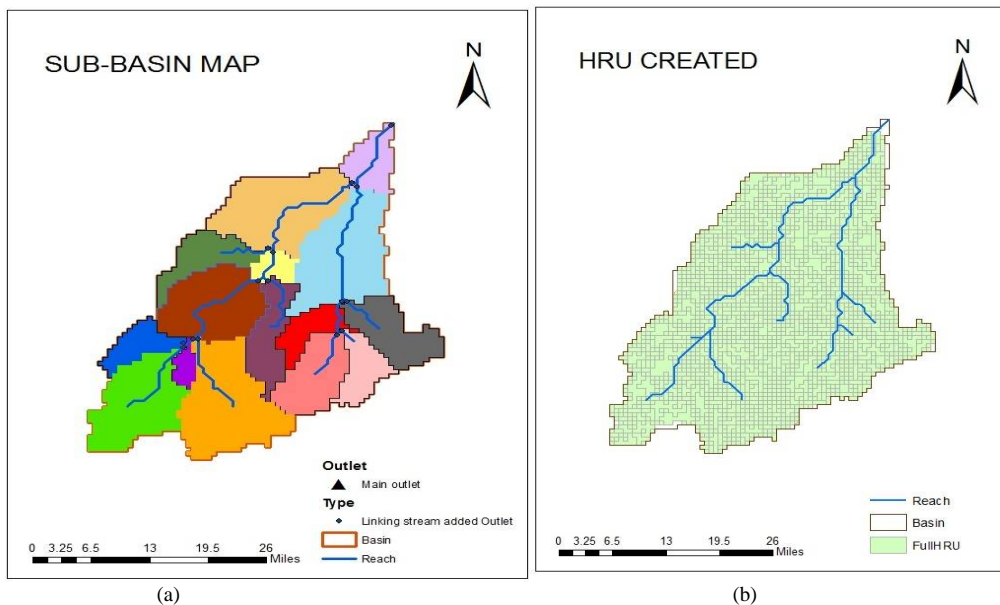


Fig. 3. (a)Sub basins delineation Map (b)HRUs created by QSWAT

DEM has been extracted from the SRTM data and was processed to accomplish the delineation and constructing the drainage. Fifteen sub basins were created as shown in Figure.4. SWAT uses a two-level disaggregation scheme; a preliminary sub basin identification was carried out based on topographic criteria, followed by further discretization of the sub-basin into Hydrological Response Units (HRUs) using landuse and soil type as input layers. The land use, soil and slope maps were overlaid. To eliminate minor landuse, soil and slope, threshold percentage method was adopted and 10% threshold for land use, 10% threshold for both soil and slope were used. Hydrologic response units for each sub basin were created as shown in Figure.3(b). This increases the accuracy. HRUs are hydrological response units that divides the watershed into various homogeneous units based on the landuse, soil type, and slope at each grid. Daily rainfall, maximum and minimum temperature data were obtained from Institute of Water Studies, Tharamani, Chennai. In the absence of other daily weather data on solar radiation, wind speed and relative humidity, long term statistics were used to generate these weather parameters. These parameters were used for the calculation of evapotranspiration. The rainfall grid and temperature grid were superimposed on the sub-basins, for deriving the weighted means of the inputs for each of the sub-basins. Landuse category was used to specify the landuse layer and soil look up table is used to specify the type of soil to be modeled for each category. Reservoir inflow and outflow data were used to define the monthly outflow data from the reservoirs along with the monthly demands and desirable rule curve levels. The files were successfully rewritten and stored in personal geodatabase of the model. After this, the model was run to simulate the surfacerunoff.

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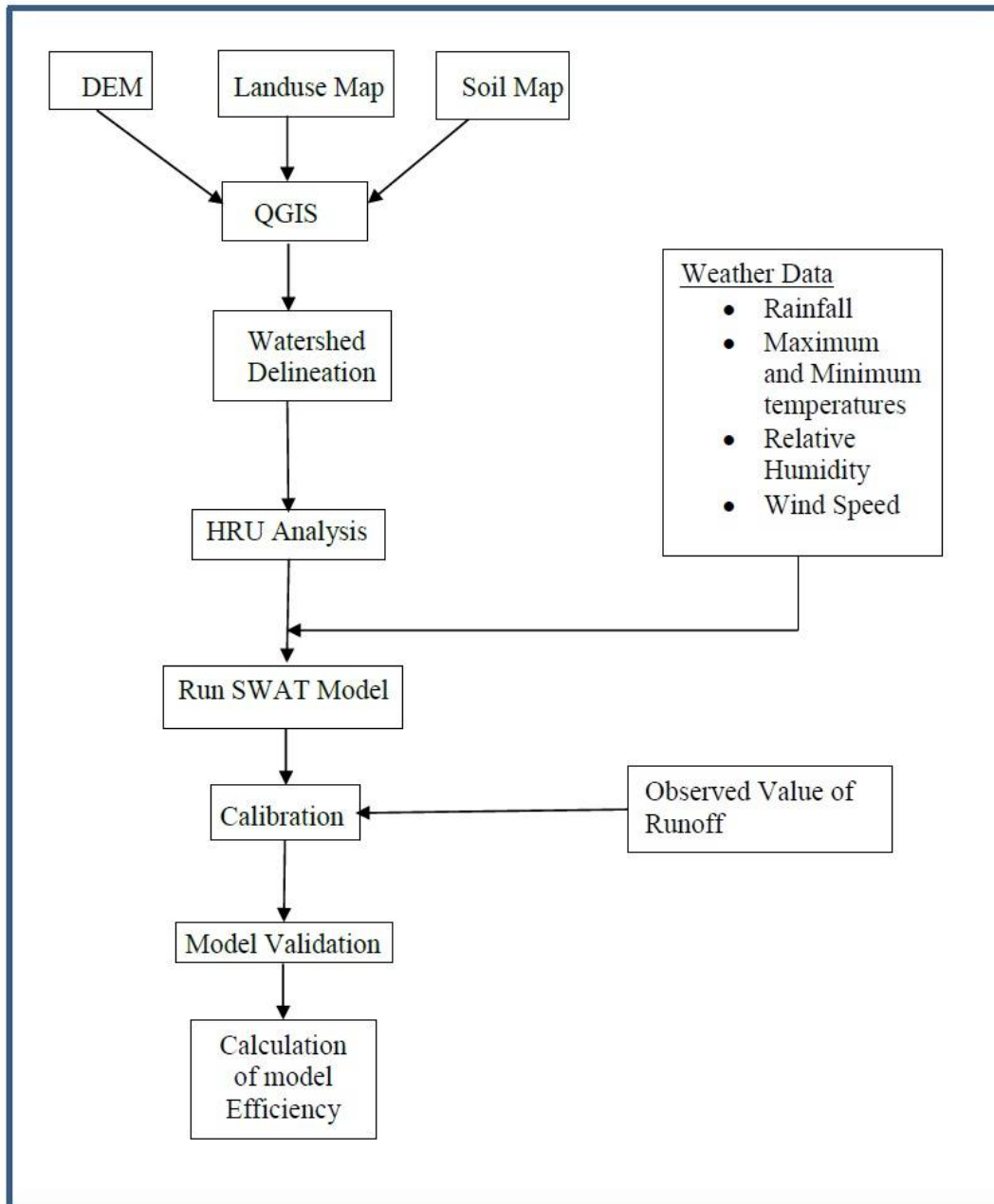


Fig. 4. Methodology Flowchart

II.3. Performance Evaluation of the Model

Literature survey focused on parameter selection reveals that some 18 parameters can be used for runoff simulation. Sensitivity analysis was carried out to identify the most sensitive parameters for the model calibration. SWAT-CUP version 2 was used to calibrate and validate the model. The sensitive parameters were automatically calibrated using

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the Sequential Uncertainty Fitting (SUFi2) algorithm. Sensitivity analysis was done by varying the various inputs of the model one by one and observing the corresponding variation in the output. The results from calibration reveals that the following eight parameters have given good performance of the model for the study area. The parameters used for simulation were curve number (CN2), base flow alpha factor (ALPHA BF), groundwater delay time (GW DELAY), threshold water depth in the shallow aquifer (GWQMN), soil evaporation compensation factor (ESCO), available water capacity (SOL AWC), saturated hydraulic conductivity (SOL_ K) and (SURLAG) surface runoff lag time. Model performance evaluation is necessary for the verification of the robustness of the model. Results of the calibration and validation were evaluated based on the visual comparison and statistical criteriasuch as, Nash Sutcliffe Efficiency (NSE), coefficient of determination (R^2), relative volume error (% error), root mean square error (RMSE) and mean absolute error (MAE), sum of square residuals (SSQR), p-factor and r-factor. Studies over various sources has been carried and model performance co-efficient are tabulated in Table.2.

III.RESULTS AND DISCUSSIONS

III.1. Calibration and Validation

The watershed was delineated and discretised into 15 sub-basins using a 90 m resolution DEM. The model was run for 15 years on monthly basis. As concern with the data availability throughout the year, selected years were used for model calibration and validation. The simulated model was calibrated for six years data from 2003 to 2008 out of which first three years years were used for warming up the model and validated for three years from 2009 to 2011. The outflow of the sub-basin 15 was taken for calibration and validation. Calibration was done for 500 simulations and the results are shown in Table.2 below:

Table (1) Model Performance Coefficients and Remarks

Sl.No.	Performance Co-efficients	Range	Description
1	Nash-Sutcliffe Coefficient [NSE] Measures the efficiency of the model by relating the goodness-of-fit of the model to the variance of the measured data[5]	$-\infty$ to 1	1- perfect match of modelled discharge to the observed data. 0 - model predictions are as accurate as the mean of the observed data <0 - the observed mean is a better predictor than the model.
2	Coefficient of Determination [R^2] Measure of how well observed outcomes are replicated by the model.[5]	0 to 1	0 - No correlation 1- desperation of the prediction is equal to that of the observation
3	P factor Percentage of observed data enveloped by our model result.[5]	0 to 1	1 - Simulation exactly corresponds to measured data
4	R factor Thickness of percentage prediction uncertainty envelope[5]	0 to ∞	0 - Simulation exactly corresponds to measured data

Table (2) Model Performance Evaluation Coefficients for Calibration of Monthly Flow (SUFi2)

Goal Type	Variable	p_factor	r_factor	R^2	NSE
Nash-Sutcliffe	FLOW_OUT_15	0.96	0.29	0.74	0.56

The SWAT flow predictions were calibrated against monthly flows from 2003 to 2008 at the gauging station. Figure 4 below shows the co-efficient of determination (R^2) for observed vs simulated flow for the calibrated years.

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The simulated monthly flows show good match with the observed values for the calibration period (2003-2008) with NSE and R^2 equal to 0.56 and 0.74 respectively.

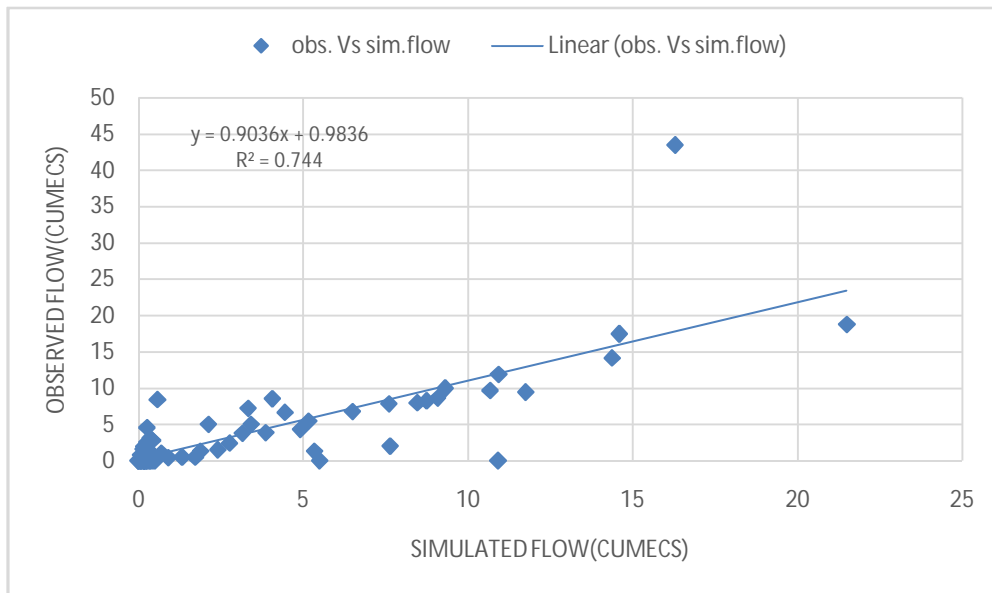


Fig. 4. Monthly Flow Calibration Plot

Table (3) Model Performance Evaluation Coefficients for Validation of Monthly Flow (SUFi2)

Goal Type	Variable	p_factor	r_factor	R ²	NS
Nash-Sutcliffe	FLOW_OUT_15	0.67	1.26	0.78	0.61

The results obtained indicates that the SWAT model reasonably simulated the basin response at the Amaravathi sub-watershed using the given set of parameters.

IV. CONCLUSION

Results obtained from the calibration and validation gives the co-efficient of determination (R^2) as 0.74 and 0.78 respectively for monthly flow analysis. The NSE values from the performance evaluation for calibration and validation are 0.56 and 0.61 respectively. It could be still perfected by field study and ensuring data accuracy through secondary data collection. Performance of the model could be increased by adding management practices, which includes agriculture practices, landuse/landcover change analysis and detailed study of groundwater usage from the deep aquifers, etc. Studies are under progress for analyses of water balance of the study area, by defining the rainfall and the analysis of percentage of predicted water balance annually.

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BIOGRAPHY



Postgraduate Scholar of Hydrology and Water Resources Engineering from CEG, Guindy Anna University, Chennai. Bachelors in Civil Engineering with University Rank 12. She is interested in Water Management in local level with efficient models and practices.



Assistant Professor(Sr.Grade) at Centre for Water Resources, Anna University, Chennai. She is specialized in Integrated Water Resources and Management and Micro level Irrigation Water Management. She has guided several M.E thesis and trained SAWA(South Asia Water) fellows in Interdisciplinary Water Resources studies.