Agriculture Association of Textile Chemical and Critical Reviews Journal (2023) 265-269

AATCC Review

27 November 2022: Received
19 March 2023: Revised
24 June 2023: Accepted
02 July2023: Available Online

www.aatcc.peerjournals.net

Research Article Open Access

Parametrization and Uncertainty analysis of SWAT model for streamflow prediction in the Palar sub-basin of Tamil Nadu

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ABSTRACT

For efficient agriculture and flood risk reduction, the Palar sub-basin requires strong water asset management. For hydrological demonstration, A semi-circulated based model, SWAT, was chosen and created in the Palar sub-basin. As part of the validation and calibration process, the Sequential Uncertainty Fitting (SUFI-2) approach was applied to the SWAT CUP model (SWAT-Calibration and Uncertainty Programs).The seven-year observed daily series of inflow data was used to calibrate and validate the SWAT model (2003-2012). The initial three years (2003-2005) were used to set the warm-up period in the SWAT model. The subsequent four years (2006-2009) were used for calibration and the remaining three years (2010-2012) for validation. Two variables, the p-factor, and the r-factor, were used to assess the competence of model validation and calibration. The calculated P-factor and r-factor for validation were 0.84 and 0.24, respectively. The P-factor with high value (0.84) expressed that 84 percent of observed inflow fell within the model uncertainty range (95 PPU). As the r-factor describes the thickness of the uncertainty band, less r-factor of 0.24 indicated the lower predictive uncertainty of the model during the validation stage. The further predictive capability of the model was quantified by PBIAS, RSR, and R2. The presence of high agreement between the observed and simulated stream flow was shown by R2 values of more than 0.8 for calibration (0.81) and validation (0.85). The NS value above 0.7 during calibration (0.75) and validation (0.8) also stated the good performance of the model. PBIAS demonstrated a smaller deviation of simulated values from the observed values by 13.3 and 11.5 % for the calibration and validation phase respectively. The discoveries would be valuable to the hydrological local area, water resource administrators working in Agriculture and soil water protection, policymakers and managing catastrophes like dry spells and floods.

Keywords: *Sensitivity, SUFI-2, SWAT-CUP, Streamflow, Uncertainty, Calibration, Validation*

INTRODUCTION

Due to the peculiarity of the research elements, the Soil and Water Assessment Tool (SWAT) Model was utilized in this study to understand the hydrological process of the Palar sub-basin. The goal of this study is to test and assess SWAT model use and performance, as well as to model hydrological parameters with judicious accuracy. Hydrological understanding could open the gates of agricultural productivity estimates using Crop Simulation Models as key components. This is extremely helpful in determining the best time for deficit irrigation to save the crop [3]. Thinking about this, the essential objective of this work was to reproduce streamflow in the Palar sub-basin utilizing the SWAT model, which was joined with model alignment and vulnerability investigation utilizing the SUFI-2 methodology, and to assess its reasonableness for the Palar sub-basin. This modeling work also helps water resource managers plan and manage agricultural water resources more effectively.

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DOI: https://doi.org/10.58321/AATCCReview.2023.11.03.265

Materials and Methods

2.1 Study area

Palar sub-basin is one among the sub-basins of the Parambikulam Aliyar Project (PAP) basin, which is an inter-state water distribution project located in the southwestern part of the peninsular India as a collaboration between Kerala and Tamil Nadu States. This project diverts the water from the eight rivers. The PAP basin area lies in coordinates of 10° 10' 00" N to 10°57'20" N latitude, 76°43'00" E to 77° 12'30" E longitudes and covers 2388.72 sq. km area (Fig.1). .In this study Palar sub-basin which was considered to be the major sub-basin of PAP basin was taken for SWAT simulations.

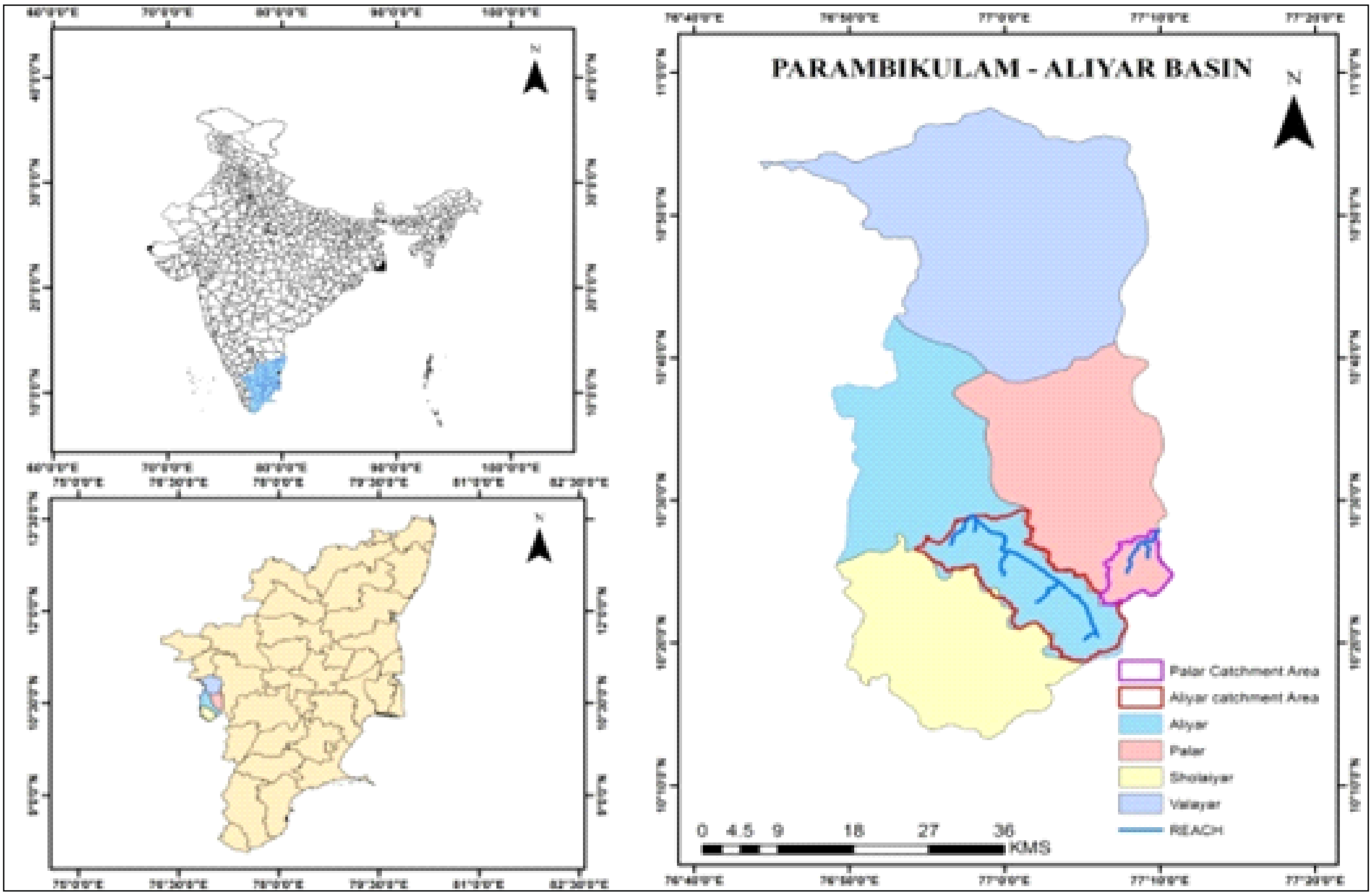

Figure 1. The study area of ParambikulamAliyar basin

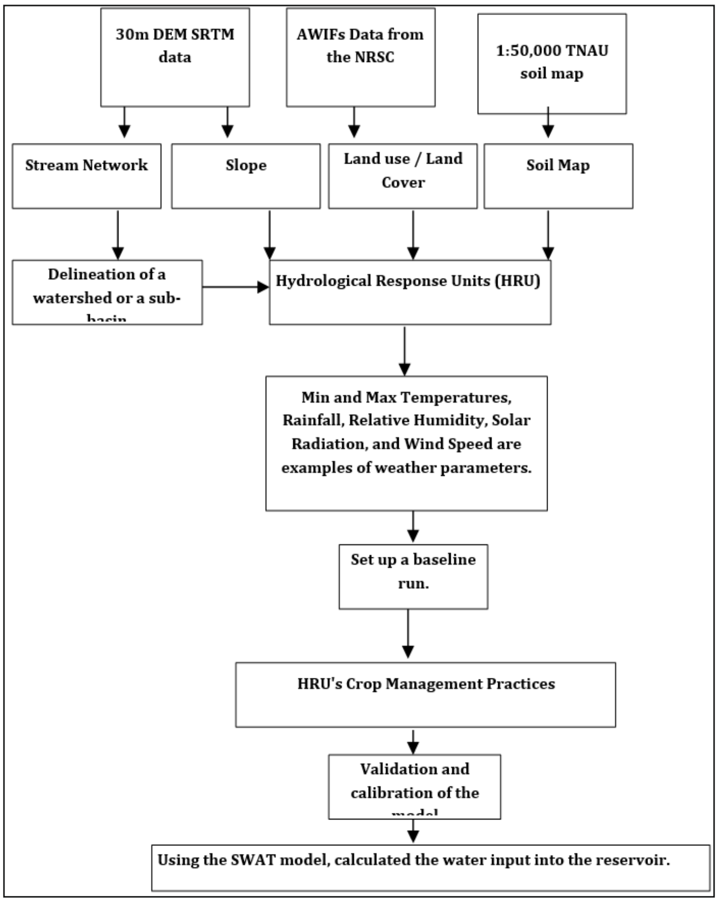

Figure 2. Schematic diagram of the Input and Output files of the SWAT model

Climate data

Data from ECMWF reanalysis Interim (ERA-I) with 0.75° horizontal resolution was used to create the starting and boundary conditions for the Weather Research and Forecasting model (WRF) [2]. To adjust for bias, the observed data was compared to the data from the simulation. Bias-corrected data was used for this study.

SWAT model

The Schematic diagram of the Input and Output files of the SWAT model is described in Fig 2.

Description of datasets used to set up the SWAT model

It was ArcSWAT 2012 that we employed in this research [6]. Soil, land use, and climate are all factors that must be taken into account while constructing the SWAT model. For the SWAT model, the Digital Elevation Model (DEM) is essential because it offers digital topographic information that helps with stream flow and watershed delineation (Fig 3.3). Shuttle Radar Topographic Mission's Digital Elevation Model of 1 Arc Second (30m) was utilized in the investigation[6]. The Parambikulam-Aliyar basin's SRTM-DEM elevations ranged from 140 to 2498 meters.

Soil data

The soils of the Tamil Nadu section of the basin were defined using a digitized soil map of Tamil Nadu at a scale of 1:50,000 acquired from the Department of Remote Sensing and Geographical Information System, Tamil Nadu Agricultural University (TNAU).

Data on land usage and land cover

The National Remote Sensing Centre provided data on land use/land cover for the year 2011. (NRSC). The NRSC created this using multi-temporal Resourcesat-1 AWiFS (Advanced Wide Field Sensor) data.

SWAT model setup

Through the GIS interface ArcSWAT2012, the streams of the Palar sub-basins catchment area were delineated using SRTM DEM and a digitised stream network from Google Earth. The Palar sub-basin was split into three sub-basins and three hydrological response units.

2.10 Calibration and validation of SWAT model

SWAT model calibration and validation were performed using the seven years observed daily series of inflow data (2003-2012). The initial three years (2003-2005) were used to set a warm-up period in the SWAT model. The subsequent four years (2006-2009) were used for calibration (Fig 2.) and the remaining three years (2010-2012) for validation (Fig 3.).SWAT-CUP is an automated model calibration tool for the SWAT model. It stands for Calibration and Uncertainty Programs. This tool was created by the Eawag Aquatic Research Institute in Switzerland [1]. SWAT-CUP is a freeware application with a generic interface. Within SWAT-CUP, several sensitivity analyses, calibrations, validations, and uncertainty analyses are possible. SWAT-CUP includes five distinct uncertainty algorithms (SUFI-2, PSO, MCMC, ParaSol, and GLUE) [1]. The unknown model parameters are systematically modified in SWAT-CUP, and the model is run. The appropriate outputs from the model output files are then extracted and compared to the observed data.SWAT-CUP was calibrated and validated using the Sequential Uncertainty Fitting (SUFI-2) method (Calibration and Uncertainty Programs). SWATCUP was calibrated by using p-factor and r-factor, which reflect model prediction uncertainty (95 PPU) as well as r-factor to determine uncertainty band thickness (PBIAS), Nash-Sutcliffe efficiency (NSE) [5], and Coefficient of determination (R2) were also calculated using the equation from 1,2,3.

The percent BIAS was computed using the following formula --- (1)

$$PBIAS = \left[\frac{\sum_{t=1}^{T}(f_t - y_t)}{\sum_{t=1}^{T}(y_t)}\right] \times 100$$

The Nash-Sutcliffe Efficiency (NSE) was computed using the following formula ---(2)

$$NSE = 1.0 - \sum_{t=1}^{T} \frac{(y_t - f_t)^2}{\sum_{t=1}^{T}(y_t - \bar{y})^2}$$

The coefficient of determination (R2) was computed using the following formula --- (3)

$$R^2 = \left\{\frac{\sum_{t=1}^{T}(y_t - \bar{y})(f_t - \bar{f})}{[\sum_{t=1}^{T}(y_t - \bar{y})^2]^{0.5}[\sum_{t=1}^{T}(f_t - \bar{f})^2]^{0.5}}\right\}^2$$

3. Result and Discussion

3.1 Sensitive analysis of parameters in SWAT cup in Palar sub-basin of PAP basin

For SWAT model calibration 15 parameters were considered based on the sensitivity levels tested in SWAT-CUP. The initial minimum and maximum values, methods used in parameter change and fitted value of individual parameters during calibration for Palarsub-basin are furnished in Table 1.

Table 1. Sensitive hydrological parameters included for calibrating the SWAT model in Palar sub-basin

Parameters name	Description	Method of change	Minimum	Maximum	Fitted value
CN2.mgt	The soil water state is represented by a curve number.	Relative	-0.12	0.41	0.09
ALPHA_BF.gw	The alpha factor for base flow (days)	Replace	0.036	0.53	0.19
GW_DELAY.gw	Delay in groundwater (days)	Replace	45	465	409
GWQMN.gw	Return flow requires a minimum depth of water in the shallow aquifer (mm).	Replace	0.08	0.31	0.16
ESCO.bsn	Compensation factor for soil evaporation	Replace	0.15	0.81	0.64
OV_N.hru	For overland flow, Manning's n value	Replace	-0.09	-0.18	-0.06
EPCO.hru	Compensation factor for plant uptake	Replace	0.35	0.81	0.45
REVAPMN.gw	The minimum depth of water in the shallow aquifer required for "recap" to take place (mm).	Replace	181	1450	308
CH_K2.rte	Alluvium in the main channel has a high effective hydraulic conductivity.	Replace	18.5	108.1	23.1

CH_N2.rte	For the primary channel, Manning's "n" value.	Replace	0.15	0.63	0.53
MSK_CO1.bsn	The calibration coefficient is used to manage the storage time's influence. constant for normal flow.	Replace	0.85	6.1	3.56
SURLAG.bsn	lag time for surface runoff	Replace	0.83	15.8	3.9
GW_REVAP.gw	Coefficient of "revap" in groundwater	Replace	0.015	0.28	0.23
RCHRG_DP.gw	Percolation fraction in deep aquifers	Replace	0.05	0.45	0.33
SOL_AWC(1).sol	The initial soil layer's available water capacity (mm/mm)	Replace	-0.15	0.18	0.15

Table 2. SWAT model statistics for calibration and validation of streamflow in Palar sub-basin

Parameters	P-factor	r-factor	R^2	NS	PBIAS	RSR
Calibration	0.78	0.26	0.81	0.75	13.3	0.6
Validation	0.84	0.24	0.85	0.8	11.5	0.45

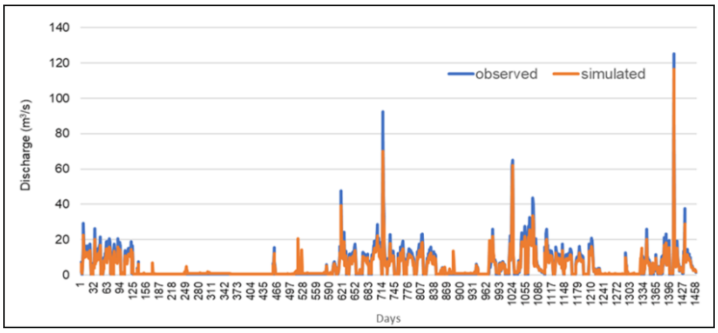

Fig . 2. Calibration of simulated stream flow with the observed stream flow (2006-2009) in Thirumoorthy reservoir in the Palar sub-basin

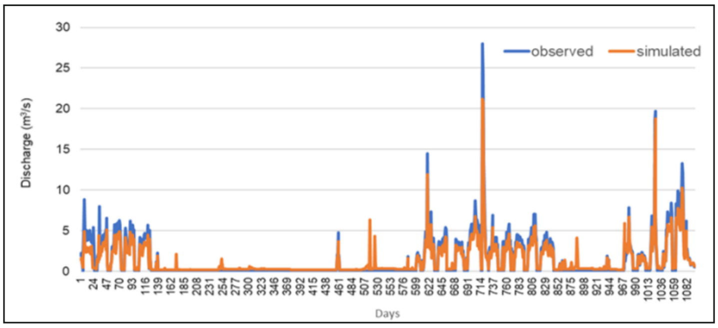

Fig . 3. Validation of simulated stream flow with the observed stream flow (2010-2012) in Thirumoorthy reservoir in the Palar sub-basin

The calculated P-factor and r-factor for validation were 0.84 and 0.24, respectively. The strong P-factor (0.84) meant that 84% of the measured inflow was within the model's uncertainty range (95 PPU). Because the r-factor defines the thickness of the uncertainty band, a lower r-factor of 0.24 indicates that the model's prediction uncertainty during the validation stage is smaller.

The objective function used for parameterization was the Nash Sutcliffe coefficient (NS) [5]. The further predictive capability of the model was quantified by PBIAS, RSR and R2. The R2 value was more than 0.8 for calibration (0.81) and validation (0.85) indicating the existence of good agreement between the observed and simulated stream flow (Table 2). The model's high performance was further demonstrated by NS values over 0.7 during calibration (0.75) and validation (0.8).PBIAS demonstrated a smaller deviation of simulated values from the observed values by 13.3 and 11.5 % for the calibration and validation phase respectively.

Conclusion

Rigorous model calibration is essential for hydrological prediction, such as discharge, to achieve an efficient outcome. It is necessary to report the uncertainty in the model forecast along with the outcomes for appropriate modeling practice. As part of this work, the SWAT model was used to simulate streamflow in the Palar sub-basin of the PAP basin, after a thorough calibration and validation method. When it comes to forecasting water flow and quantifying uncertainties and related assumptions, SWAT CUP has been demonstrated to be a significant tool. As per the consequences of the alignment and approval, the model precisely duplicated the noticed streamflow. The discoveries of this study might be helpful in water management in agriculture, soil and water preservation, and lessening catastrophic events like dry spells and floods, among different applications.

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