Calibration, validation and uncertainty analysis of SWAT Model for predicting reservoir inflow in Umiam watershed, Meghalaya.

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Abstract— **The prediction of inflow to a reservoir is of utmost importance for the optimal operation of the reservoir. Umiam watershed is of great significance to the Meghalaya State of India as it serves five major reservoirs for generation of hydropower. The objective of this study is to calibrate and validate the Soil and Water Assessment Tool (SWAT) model for Umiam watershed in Meghalaya, India for predicting reservoir inflow and to quantify the uncertainties. The SWAT model was configured for Umiam basin and the calibration, validation and uncertainty analysis of the model was carried out using SUFI-2 algorithm. The model was calibrated using the reservoir inflow data obtained from mass balance calculation for the period 1979 – 1995 and validated for the period 1996-2000 on monthly basis. The sensitivity analysis shows that the parameters such as Curve Number, Groundwater Delay Time, Groundwater Revap Coefficient, Saturated hydraulic conductivity, Baseflow Alpha Factor, HRU Slope, Soil Evaporation Compensation Factor, Available water capacity of the soil are very sensitive ($p < 0.05$). The streamflow simulated by the model showed a good correlation with the observed data with R^2 values of 0.96 and 0.86 for calibration and validation periods respectively. From this study, it can be concluded that SWAT model can be used to predict reservoir inflow in Umiam Watershed.**

Keywords— Sensitivity; Uncertainty; SWAT-CUP.

I. INTRODUCTION

Hydrologic models serves as an important tool for quantifying inflows to reservoirs and thus help in planning and management of water-use in a catchment [1], [2]. However, natural processes are difficult to predict using simple mathematical equations and thus, there is always some uncertainty associated with hydrological models [3]. Before a hydrological model is considered satisfactory for decision-making process, its uncertainties emerging from model structure, parameters and input data, needs to be analysed and quantified [4].

SWAT is amongst the most widely used public domain hydrologic models for watershed scale studies and has been applied world wide [5]–[7]. K. C. Abbaspour et al., (2015) applied SWAT model on a continental scale for Europe to study hydrology and water quality. SWAT was used by Gosain et al. (2006) for studying impact of climate change in 12 major river basins in India. On a smaller scale, Pandey et al., (2017) employed SWAT model for Armur watershed in Godavari river basin, India, which had an area of 20,319 hectares. SWAT model has large number of parameters which makes manual calibration of parameters in SWAT model a tidious task. Therefore, SWAT-CUP (Calibration and Uncertainty Program) was ensued to facilitate automatic calibration of SWAT parameters and carry out uncertainty analysis [10].

Umiam Stage 1 reservoir in Meghalaya serves five cascading hydropower stations in the area. Thus, it is important to have a hydrologic model that is capable of simulating its inflow. The calibrated model can be used to predict reservoir inflow taking into account changes in climatic conditions and will help the authorities in management of reservoir water. In this study, we use SUFI-2 (Sequential Uncertainty Fitting) algorithm in SWAT-CUP to evaluate the applicability of SWAT model in Umiam Watershed and to analyse the uncertainties.

II. STUDY AREA

The Umiam River flows from Sawlad village, south of Shillong and flows through Shillong City till it reaches Umiam Stage 1 reservoir. The watershed area is located between the longitudes 91.67 and 91.95 and latitudes 25.45 to 25.67, at a distance of 15 km to the North of Shillong. The watershed has an area of 218.4 Km^2. Elevation ranges from 1962 m in the upstream region to 976 m near the reservoir.

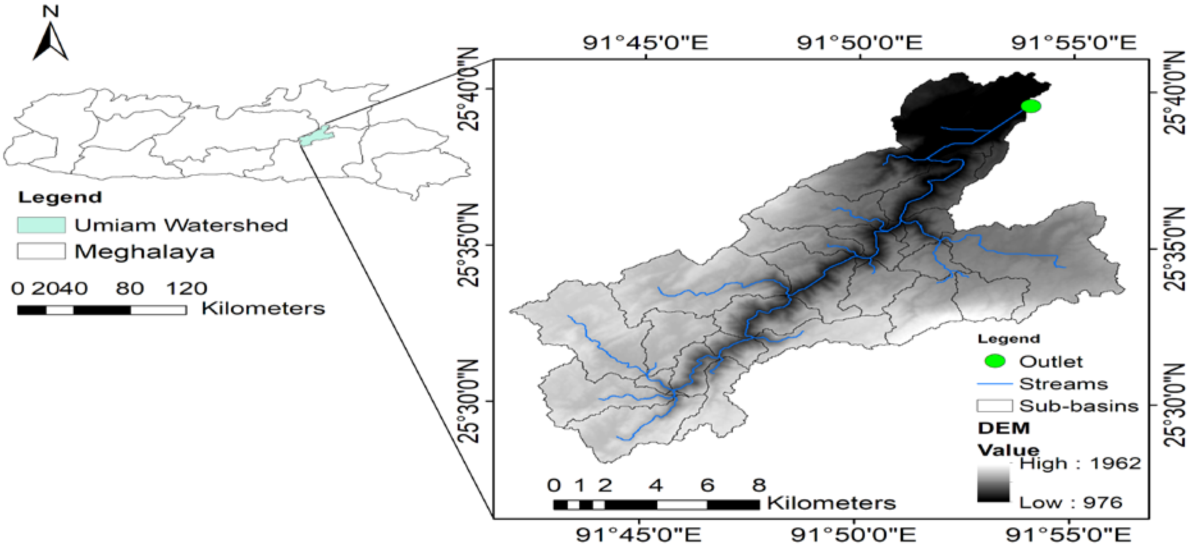

Fig. 1 Map showing Umiam Watershed and its topographic features

The area experiences heavy rains during monsoon and cold winters. The minimum temperatures ranges from 13.95°C to 16.70°C in winter and maximum temperature varies from 22.08°C to 26.47°C in summer. The watershed receives annual average rainfall of 3385 mm.

III. DATA

SWAT requires topographic, pedologic, landuse and land cover, and meteorological data for model building and simulations. In this study, the SRTM DEM of 30 m is used for watershed delineation and creating reaches in ArcSWAT interface. The soil map was extracted from Harmonized World Soil Database (HWSD), as defined in FAO-UNESCO Soil Map of the World. Land use and land cover (LULC) data of 500 m resolution was obtained from USGS Land Cover Institute website [11]. The daily precipitation and temperature data are derived from gridded dataset prepared by Indian Meteorological Department (IMD). The data for other parameters like humidity, solar radiation and wind are simulated using the inbuilt weather generator in SWAT due to unavailability of data. The monthly inflow data of Umiam Stage 1 reservoir were collected from Meghalaya Power Generation Corporation Limited (MePGCL), Shillong.

IV. METHODOLOGY

A. Watershed configuration

Watershed delineation is done using automatic watershed delineator in ArcSWAT. 31 sub-basins are formed after delineation. Next input is soil and vegetation cover information which is crucial in the water movement process and forms an important input for hydrologic simulation [16], [17]. We reclassified LULC raster into 9 classes according to SWAT LULC code. There are two soil types in the study area according to FAO data i.e. Ao74-2b-3646 and Ao75-2b-3647,

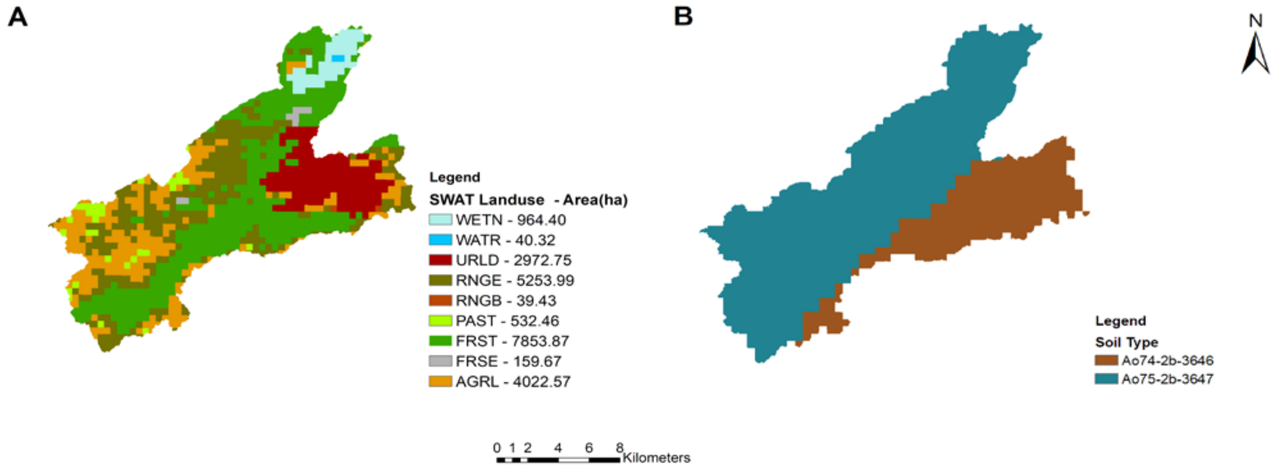

Fig. 2 Land Use and Land Cover Map (A) and Soil Map (B) of Umiam Watershed

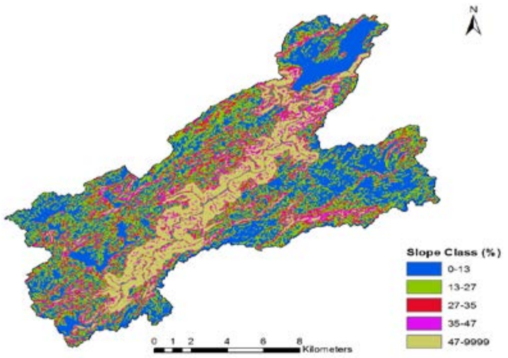

Fig. 3 Slope Map of Umiam Watershed

both belonging to dominant soil group called Orthic Acrisols. Five slope classes are defined based on slope map of the area (Fig. 3). Based on the LULC, soil and slope combinations, 258 Hydrologic Response Units (HRU) are formed.

B. *Sensitivity Analysis*

SWAT model simulates complex hydrological processes and therefore has over 200 hydrological parameters. A sensitivity analysis is carried out to distinguish the most sensitive parameters that influence the model output in the study area. Based on the sensitivity analysis, we can reduce the number of parameters to be used for calibration by eliminating the less sensitive parameters [18]. The sensitive parameters represent the most important processes in the study area. Arnold et al., (2012) categorized the parameters from 64 studies based on the processes they represent. In this study, we select 15 parameters based on literature for sensitivity analysis which influence hydrology and streamflow. Sensitivity analysis was done using all at a time sensitivity method.

C. *Model Calibration, Validation and Uncertainty Analysis*

The model calibration, validation, and uncertainty analysis are done using SUFI-2[12] algorithm in SWAT-CUP program [13]. In the SUFI-2 algorithm, all the uncertainties associated with the model such as parameter, conceptual, model and input uncertainty are accounted by parameter ranges. The parameters are sampled using the Latin Hypercube sampling method and uncertainties are propagated and reflected in the 95 percent prediction uncertainty (95PPU) band of SUFI-2 output. Initially, SUFI-2 assumes a wider range of 95PPU to include observed data under that range. This bracketing of observed data by 95PPU is measured by an index called p-factor which ranges from 0 to 1 (where 1 signifies complete bracketing of observed data within 95PPU region). The SUFI-2 algorithm gradually reduces the uncertainty range to acceptable range called r-factor. Smaller r-factor indicates better calibration performance. The iteration is continued until the 2.5th percentile and 97th percentile brackets most of the observed data under a specified objective function, which is R^2 in this case.

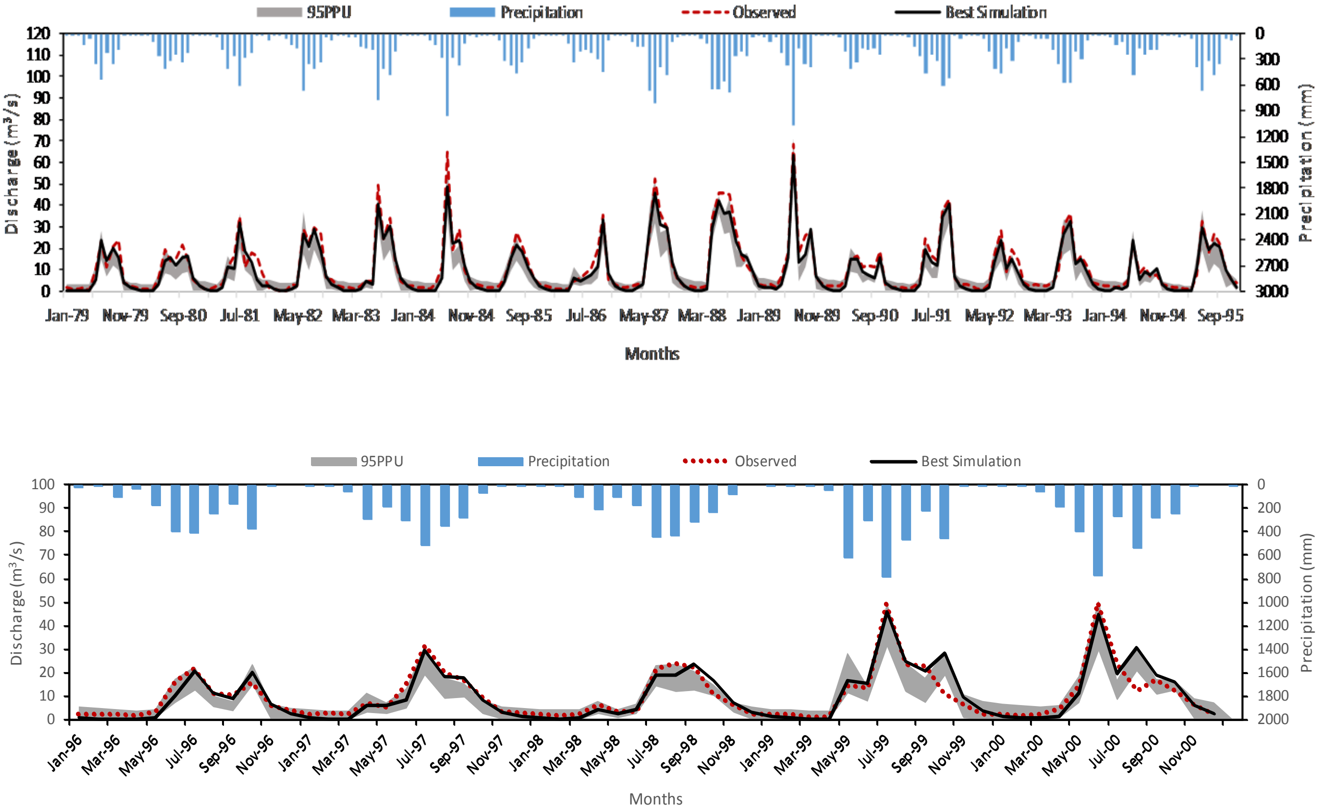

Fig. 4 95PPU (shaded region) from SUFI-2 output. Calibration period at the top and validation period at the bottom.

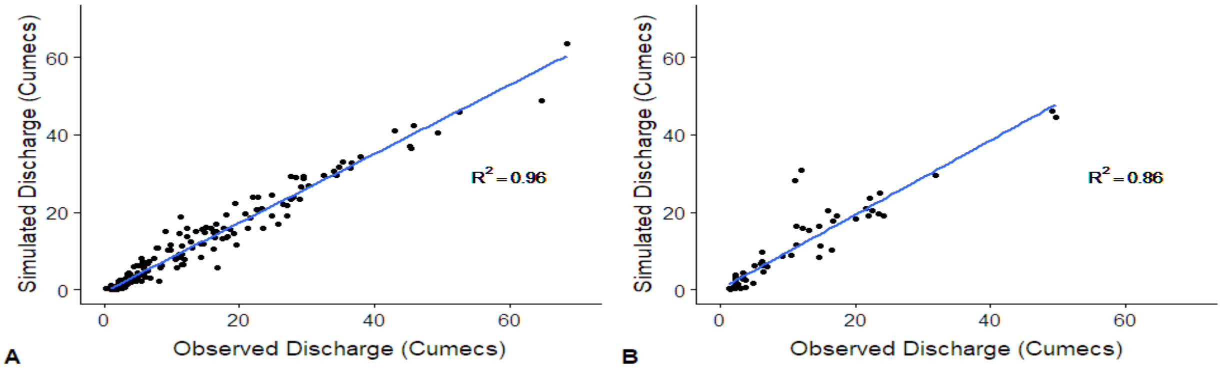

Fig. 5. Scatter plot of Observed vs. Simulated flow during Calibration (A) and Validation (B)

The SWAT model is run for 22 years, from 1974 to 1995. A warm-up period of 5 years is used thus, the effective period of simulation started in 1979. Validation is done for the period 1996 to 2000 using monthly observed flow data. For each iteration, 500 simulations are carried out and after each iteration, parameter values are replaced by new values suggested by SWAT-CUP. A total of 4 iterations lead to satisfactory model performance and no further improvement was observed in the objective function i.e. R^2.

V. RESULTS AND DISCUSSION

A. *Sensitivity Analysis*

The sensitivity of parameters is determined based on p-value and t-statistic given by global sensitivity test in SWAT-CUP. The sensitivity analysis revealed that the most sensitive parameters are CN2, GW_Delay, GW_Revap, SOL_K, ALPHA_BF, HRU_SLP, ESCO and SOL_AWC. These parameters can be said to represent the rainfall-runoff process in the watershed. Most of the sensitive parameters mentioned above are found to be sensitive in several other studies [14]–[17].

B. *Calibration and Validation*

The model is calibrated using monthly flow data for 17 years (1979-1995) and validated for 5 years (1996-2000) (Fig. 4). The calibrated parameter ranges are shown in Table 1. The prefix R and V before the parameter names in Table 1 signifies relative change and replacement methods of altering the

TABLE 1 Calibrated Parameter ranges

Sl. No	Parameter	Description of Parameter	Lower and Upper Bounds	Fitted Value	Sensitivity Rank
1.	R__CN2.mgt	SCS runoff curve number	-0.20 to 0.20	0.034	1
2.	V__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0 to 25	21.37	15
3.	V__GW_REVAP.gw	Groundwater "revap" coefficient	0.02 to 0.2	0.073	3
4.	V__REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0 to 10	9.79	12
5.	V__ESCO.hru	Soil evaporation compensation factor	0.8 to 1	0.85	7
6.	V__EPCO.hru	Plant uptake compensation factor	0.8 to 1	0.87	10
7.	R__OV_N.hru	Manning’s “n” value for overland flow	-0.2 to 0.2	0.066	14
8.	V__ALPHA_BF.gw	Baseflow alpha factor (days)	0 to 1	0.725	5
9.	V__GW_DELAY.gw	Groundwater delay (days)	30 to 450	40	2
10.	R__SOL_AWC(..).sol	Available water capacity of the soil layer (mm H2O /mm soil)	0.2 to 0.4	0.08	8
11.	R__SURLAG.bsn	Surface runoff lag time (days)	-0.3 to 0.2	0.12	11
12.	R__RCHRG_DP.gw	Deep aquifer percolation fraction	-0.2 to 0.2	0.14	13
13.	R__CH_K2.rte	Effective hydraulic conductivity in main channel alluvium (mm/hr)	-0.2 to 0.2	0.19	9
14.	R__SOL_K(..).sol	Saturated hydraulic conductivity (mm/h)	-0.8 to 0.8	0.136	4
15.	R__HRU_SLP.hru	Average slope steepness (m/m)	0 to 0.2	0.089	6

parameter values respectively [13]. The model shows very good performance in the calibration period, with slight under-prediction. From Fig. 4, it can be observed that most of the peak flows are underpredicted by SWAT. Large uncertainty can be seen in the baseflow region. The reason for inefficient baseflow simulation may be due to the inability of SWAT to accurately simulate groundwater flow [18]. The p-factor value (0.81) and r-factor (0.5) are under acceptable range recommended by K C Abbaspour et al., (2015b). The highest observed average monthly inflow during the calibration period was in July 1989 (68.41 cumecs) followed by July 1984 (64.77 cumecs). The corresponding flows simulated by SWAT were 63.59 cumecs and 48.71 cumecs respectively.

The model set up after a calibration process, needs to be evaluated by a validation process in order to test the performance of the model to a different input dataset. The calibrated model with optimum parameter values is validated for the period 1996 – 2000. During the validation period, the R^2 and NSE were slightly lower than in the calibration period, whereas, p-factor and r factor increased to 0.88 and 0.66 respectively. In the validation period, highest inflow occurred in July 2000 (49.58 cumecs) against SWAT simulated flow of 44.55 cumecs. The performance statistics of the model is given in Table 2.

TABLE 2 Model performance

Performance Index	Calibration	Validation
R^2	0.96	0.86
NSE	0.94	0.85
PBIAS	15	1.6
p-factor	0.81	0.88
r-factor	0.50	0.66

VI. CONCLUSIONS

The SWAT model was successfully calibrated and validated for Umiam watershed. The sensitivity and uncertainty analysis was also carried out for Umiam watershed using SUFI-2 scheme in SWAT-CUP. The sensitivity analysis was done for the 15 hydrological parameters, out of which the most sensitive parameters are CN2, GW_DELAY, GW_REVAP, SOL_K, REVAPMN, ALPHA_BF, HRU_SLP, ESCO, and SOL_AWC. The observed and simulated discharge shows good conformity during the calibration and validation periods. This shows that the parameters used in the simulations are able to mimic the hydrological processes taking place in the Umiam watershed. SWAT could simulate peak flows very well in the Umiam watershed while it has some limitations in simulating baseflows accurately. The model showed promising results in this study indicating that SWAT model and SWAT-CUP can be used to predict reservoir inflows and climate change study. Future studies may address the effect of landuse and climate change on streamflow in Umiam watershed.

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