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Uncertainty Analysis of Dominating Hydrological Parameters in Diverse Hydrometeorological Micro-Watersheds in Krishna Basin, India

[1]Nayeemahmed Mulla, [1,2]N.C. Mondal*

Author's Affiliations:
[1]Earth Process Modeling Group, CSIR-National Geophysical Research Institute, Hyderabad, Telangana 500007, India

[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh 201002, India

***Corresponding Author: N.C. Mondal**, Earth Process Modeling Group, CSIR-National Geophysical Research Institute, Hyderabad, Telangana 500007, India

E-mail: ncmngri@gmail.com

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ABSTRACT

Hydrological model plays a vital role in water resources management and serves many applications, including water resources planning development and management, agriculture, and flood production. Rainfall-runoff modeling in any watershed is highly influenced by the different hydrological parameters such as Curve Number (CN_2), Groundwater Delay (GW_DEALY), Base flow (ALPHA_BF), ground water Revap (GW_REVAP), Threshold depth of water (GWQM), and ESCO. Therefore, the rainfall-runoff model was simulated using the Algorithm SUFI-2 of SWAT-CUP in the Soil-Water Assessment Tool (SWAT) in two diverse hydro-meteorological watersheds of Marol (area: ~5158 km^2), and Talikot (area: ~2370 km^2) in Krishna basin of Southern India, where the unregulated flow exit. The results show that the R^2 and NSE-values for the calibration of streamflow in Marol watershed are 0.87 and 0.84, respectively, and in the validation, 0.65 and 0.58, respectively. Similarly, for the Talikot watershed, they are 0.90 and 0.52; and 0.83 and 0.74, respectively. The curve number, groundwater delay and water available capacity of the soil are the most sensitive parameters in the Marol watershed, whereas the threshold water level in the shallow aquifer for the base flow is the additional sensitive parameter. The uncertainty ranges of the different sensitivity parameters are observed for both the watersheds. The calculated coefficient of variation shows that, among the different parameters, the GW_DELAY has relatively high uncertainty, but the curve number (CN_2) and threshold depth of water (GWQMN) parameters have relatively low uncertainties.

KEYWORDS: *Hydrogeological parameters, SWAT model, sensitivity, micro-watersheds, Krishna basin.*

INTRODUCTION

To protect the economy and environment, its basic and important thing that, surface water is accessible to meet the demand of agriculture, commercial areas like industries, and the domestic areas for the future. In many parts of the countries, they are suffering from water scarcity, varying from small scale to large scale, hence the major cause of water scarcity is due to uneven distribution of water availability and lack of consideration regarding water protection, which leads to flood, drought, and natural disasters (Dawdy et al., 1972; Loague Sharad and Green 2007; Gull Dooge et al 2017; Chung et all., 2019; Prasanchum et al., 2020). Hydrological models are one of the tools available to estimate and predict the quantity and quality of water available on the surface of the earth (Baffaut et al., 2015; Aawar and Khare, 2020); hence hydrological models help in making better decisions (Chiew and McMahon, 1994). A portion of these models could likewise anticipate the effects of regular and human-centric changes on water assets and furthermore to evaluate the spatial and transient accessibility of the assets (Arnold et al., 2012; Adnan et al., 2019; Setti et al., 2020). Hydrological model is scientific mathematical representation of hydrological process (Jia et al., 2005; Sarwade et al., 2007; Kashimbiri et al., 2009; Rangarajan et al., 2009; Mondal et al., 2011, 2012; Varade et al., 2013; Venkatarao et al., 2019). The core aim of the hydrological model is to understand the hydrological behaviour in hydro-climatic conditions, and hydrological frameworks in order to facilitate dependable or solid information to protect the water resource and environmental hazards (Jia et al., 2005). Hydrological models are generally utilized for research and engineering works in the area of water quality, environment and climate change analysis (Mondal and Singh, 2012; Mondal and Ahmed, 2015; Mondal et al., 2017; Aawar and Khare, 2020), and change in the characteristic of land used and land cover (LULC), and management practices, etc. The nature of the hydrological system is briefly categorized, as to explain the complete system of hydrological behaviours. The SWAT and SWAT-CUP model was used to analyse the dominating hydrological parameter (Arnold et al., 2012; Srinivas and Gopal, 2017) for different hydrometer logical regions in Krishna basin. Hence, the development of SWAT is a continuation of USDA Agricultural Research Service (ARS) modeling experience in the year of 1990's to simulate the surface runoff, sediment transport, and nutrient transport phenomenon (Karatas, 2015; Srinivas and Gopal, 2017; Brito et al., 2019). The SWAT model is large scale watershed model used to simulate the runoff (Tyagi et al., 2014). Earlier the calibration of hydrological model was improper due to improper co-ordination of complex model's adopted and insufficient data availability (Anand et al., 2007). To overcome such problems different alternative techniques are used to evaluate the hydrological and hydrometer logical condition by statistical approaches which are used to predict the rainfall runoff modelling (Chiew et al., 1993; Gassman et al., 2015). Hence, the SWAT model acts as an appropriate mode, which incorporates an extensive number of parameters that depict distinctive hydrological conditions and qualities over the watershed (Tyagi et al., 2014; Arnold et al., 2012). Advantage of SWAT models, it is one of the best and most widely used software tools in all most all water resource projects. The software is open source available for all users. It gives comprehensive details about the software with documentation. More than 2700 papers have been presented in various international conferences worldwide (Tyagi et al., 2014; Wible 2014; Gassmann et al., 2015). The model used for the calibration and sensitivity analysis (Song et al., 2015; Vilaysane et al., 2015; Khalid et al., 2016; Srinivas and Gopal, 2017) can be determined by adding the extension program called SWAT-CUP (SUFI-2 Algorithm). Nutrition and pesticide loads can also be determined by using the SWAT model. The model is user friendly and continues development is taking place to improve the computational efficiency of the model. The SWAT model is suitable for both large and small-scale watersheds. Therefore, the rainfall-run off models are developed using the Algorithm SUFI-2 of SWAT-CUP in the Soil-Water Assessment Tool (SWAT) in Marol and Talikot watersheds in Krishna basin, and discussed in this paper.

STUDY AREA

The study area is located in the Krishna basin, which is situated in the southern part of India. This basin is located at longitude of 73°17′ to 81°09′E, and latitude of 13°10′ to 19° 22′N, respectively. With the maximum elevation of 1903 meter, above the mean sea level (m, amsl), the major areas of the Krishna basin fall in the elevation of 500-700 m, amsl. The Krishna basin is having different hydro-climatic conditions like (1) Drought zone or Arid zone), (2) Semi Drought zone or Semi-arid zone and, (3) saturation or Humid zone. Considering such different hydro-climatic conditions, two watersheds, namely Marol and Talikot were identified in Krishna basin having different climatic conditions and having unregulated flow. The location of these watersheds is shown in Figure 1.

The Marol watershed has bounded with Chigalli Watershed on the top and Kuppelur watershed at the bottom. The outlet of this watershed joins Tungabhadra River at the downstream of the Marol watershed. Marol watershed contributes the discharge to the Tungabhadra River of having drainage area of about 73.11 (km^2). Whereas the Talikot watershed is bounded with upper Bhīma catchment at the top and Almatti watershed at the bottom. The discharge from the Talikot catchment initially joins to the Doni River and continues to flow Krishna River. Talikot watershed is situated in the drought zone or arid zone of Krishna basin, and it has a drainage area of about 10.11 (km^2).

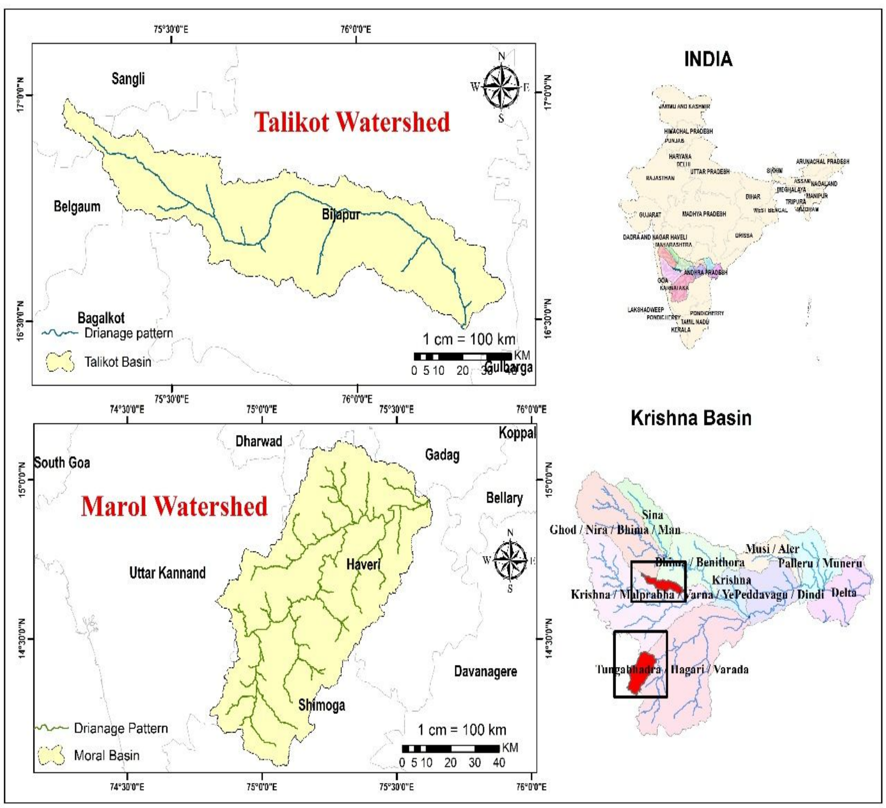

Figure 1: Location maps of Marol and Talikot watershed in Krishna basin, India

MATERIALS AND METHODS

Methodology

The methodology of the SWAT model consists of seven different steps (Srinivas and Gopal, 2017; Gull et al., 2017). They are: (1) First step is to set up the project in ARC-GIS software and creates the file name in geo-database file format. In addition, prepare the data required to delineate watershed such as DEM and LULC data, (2) Second step is to delineate the watersheds by using these data, (3) In the third step, the HRU analysis was carried out by adding the LULC data to the delineated watersheds. (4) The collected weather data is substituted to generate the built-up table in the SWAT model, (5) the next step is to set up the model to simulate in the specified period and run the simulation, (6) After simulation of the SWAT model, the simulated value was validated using the extension tool called SWAT-CUP, and (7) In the last step, the calibrated and validated results were compared with the observed discharge data, as shown in Figure 2.

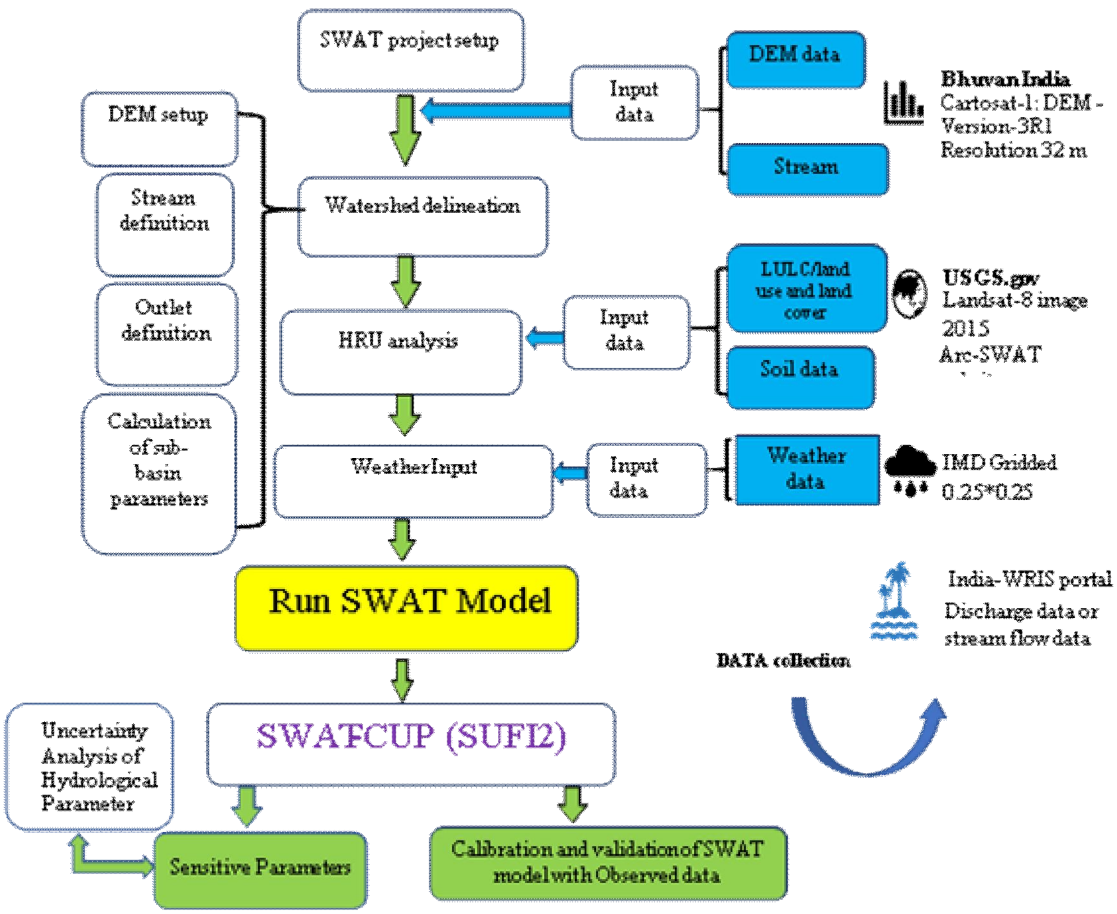

Figure 2: Flow chart of the methodology adopted for the research work

Model Performance

The efficiency of standard hydrological model is determined based on comparing simulated and observed flows, respectively. The behaviour of the simulated and results, are measured by the statistical approach of correlation measurements such as R^2 (coefficient of determination) and NSE (Nash-Sutcliffe efficiency) (Krause et al., 2005). To calibrate and validate the SWAT model, a statistical correlation approach was used to determine the R^2 and NSE values. The mathematical formulas were used to determine the R^2 and NSE values, are presented below (Krause et al., 2005; Abbaspour et al., 2015; Srinivas and Gopal, 2017).

$$R^2 = \left(\frac{\sum_{i=1}^{n}(Oi - O)(Pi - P)}{\sqrt{\sum_{i=1}^{n}(Oi - O)}\sqrt{\sum_{i=1}^{n}(Pi - P)}} \right)^2 \quad (1)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Oi - Pi)^2}{\sum_{i=1}^{n}(Oi - O)^2} \quad (2)$$

where, O = Observed discharge, and P = Predicted or Simulated discharge.

Based on the graphical representation of observed and simulated flow from the SWAT model, the performance model was analysed. By considering, the output generated from the model and hence the R^2 and NSE value were determined to evaluate the efficiency of the model. The coefficient of determination (R^2) ranges from 0 to 1.00, where 1.00 represents the very good performance of model in the prediction of simulated results. NSE ranges from ∞ to 1.00, where 1.00 represents very good performance of the model, and less than zero represents the bad performance of the model, as presented in Table 1 (Srinivas and Gopal, *2017).*

Table 1: General performance ratings for the recommended R^2 and NSE values *(after Srinivas and Gopal, 2017)*

Sl. No	Performance rating	R²	NSE
1	Very good	0.75 -1.00	0.75-1.00
2	Good	0.65-0.75	0.65-0.75
3	Satisfactory	0.50-0.65	0.50-0.65
4	Non –satisfactory	<0.50	<0.50

Uncertainty Analysis

The degrees of uncertainties for the sensitive parameters for Marol and Talikot watersheds had been calculated by the following steps (Yang et al., 2008; Vallam et al., 2014; Abaspour et al., 2015).

Step-1: The model was run for the different simulations such as 50, 100, 150, and so on. Then the mean of these simulations were calculated by using following formula.

$$\overline{X} = \frac{\sum X}{N} \quad (3)$$

Step-II: Standard deviation (SD) for the different simulations such as 50,100,150 and so on was calculated by using the following formula.

$$s = \sqrt{\frac{\sum(x - \overline{x})^2}{n - 1}} \quad (4)$$

Step-III: By using mean and standard deviation the coefficient of variation was calculated for the sensitive parameters. The coefficient of variation is expressed in percentage as below

Coefficient of variation (%) = SD / Mean (5)

Step-IV: Degree of uncertainty was assigned for the sensitive parameters of each study area based on the coefficient of variation (%) (Zhang et al., 2014). Larger coefficient of variation indicates a high degree of the uncertainty.

Data Collection

For this study, the different types of data such as DEM, soil map, Land Use Land Cover (LULC), weather parameters (like precipitation and temperature) were collected, as presented in Table 2.

1. Digital Elevation Model (DEM) data for both Marol and Talikot watersheds were collected from the Bhuvan web site (resolution: 32 m)
2. Soil maps were collected from the Food and Agricultural Organization (FAO).
3. LULC data were collected from the official website of the National Remote Sensing Centre (NRSC), Hyderabad.
4. Weather data were collected from TAMU-SWAT web site, and
5. Discharge data collected from India-WRIS. Nine-year discharge data (from 1972-80) in Marol watershed whereas 9-year data (from 1997-2005) in Talikot watershed, Krishna basin were collected for the analysis.

Table 2: **Details of the data collected**

Sl. No.	Data Type	Source	Description/ link
1	DEM	Bhuvan website	Product- Cartosat-1: DEM - Version-3R1 Resolution 32 m https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php
2	Soil	Arc-SWAT website (Indian dataset for SWAT 2012)	Soil HWSD FAO (worldwide data) http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/
3	LULC	USGS Earth Explorer (usgs.gov)	USGS land set -8 data (2015) Earth Explorer (usgs.gov)
4	Weather Data	Indian Metrological Department (IMD), Pune, India	IMD Gridded weather includes Precipitation (0.25*0.25degree) and Temperature data (1*1degree) https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html

RESULTS AND DISCUSSION

Digital Elevation Model (DEM) map of the Marol and Talikot watersheds were made based on the DEM data collected from the Bhuvan web site of having 32 m resolution. The delineation of the watershed was carried out in the SWAT model. The DEM data are most important, used to analyse the topographical parameter of the watershed such as slope, sub basin and various channel flow. The minimum and maximum elevations of the Marol watershed are 411 and 756 m, amsl, respectively and similarly in the Talikot watershed, it varied from 505 and 606 m, amsl, respectively, as shown in Figure 3.

The LULC is very important for determining the HRU's analysis of each sub-basin, because it is influencing factor to estimate the surface runoff. The LULC data were collected from official web site of National Remote Sensing Centre (NRSC) for the year 2005. The supervise calcification was adopted to classify the features. Figure 4 shows the LULC maps of Marol and Talikot watersheds. The LULC maps cover the classification of A, B, C, D, which were done as per the Food and Agricultural Organization (FAO). In this study area, there are different types of soils identified, the Marol watershed mainly consists of loam soil of about 45% area, and partial consists of clay alluvial and sandy soil, respectively.

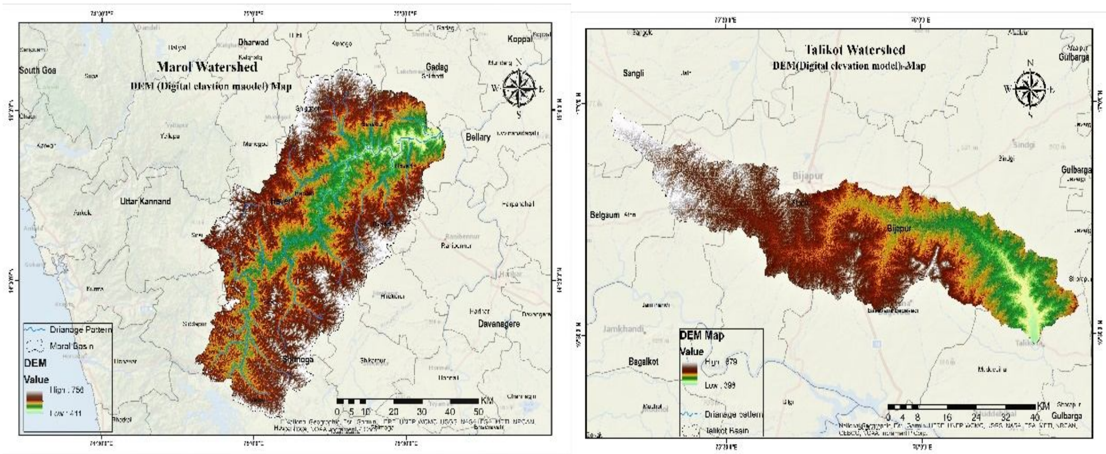

Figure 3: DEM maps of the Marol and Talikot watersheds in Krishna basin

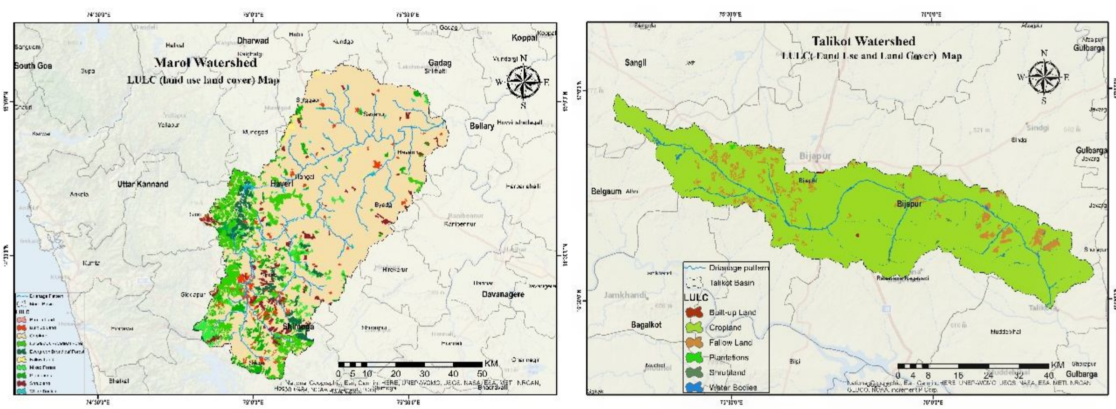

Figure 4: LULC maps of Marol and Talikot watersheds, Krishna basin

SWAT results after the calibration

In marol watershed

The calibration of the SWAT model was carried out for six years from 1972-1977 to compare the simulated results with the observed discharge. The initial two years were utilized as warm-up period for the SWAT model to avoid the effects of unknown initial condition. To calibrate the SWAT model, the parameters were chosen based on the literature review to bring the proximity in the discharge curve by comparing the simulated results with the observed discharge. Hence, the model performance after calibration was obtained as R^2 and NSE values where, R^2 as 0.87 and NSE as 0.84, respectively, as shown in Figure 5.

The validation of the SWAT model was carried out for 3 years from the period of year 1978-1980. The validation was carried out to determine the model accuracy after calibration. The values of R^2 and NSE were obtained after the validation as 0.6577 and 0.58, respectively. Figure 6 shows the time versus observed and simulated discharge for the comparison of flow and also the scatter plots of the simulated v/s observed discharge.

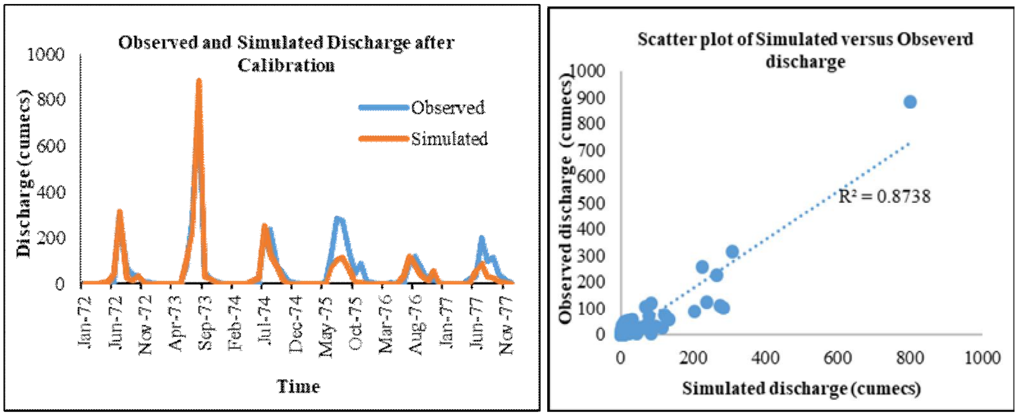

Figure 5: Comparisons of the observed with the simulated discharge after the calibration in Marol watershed

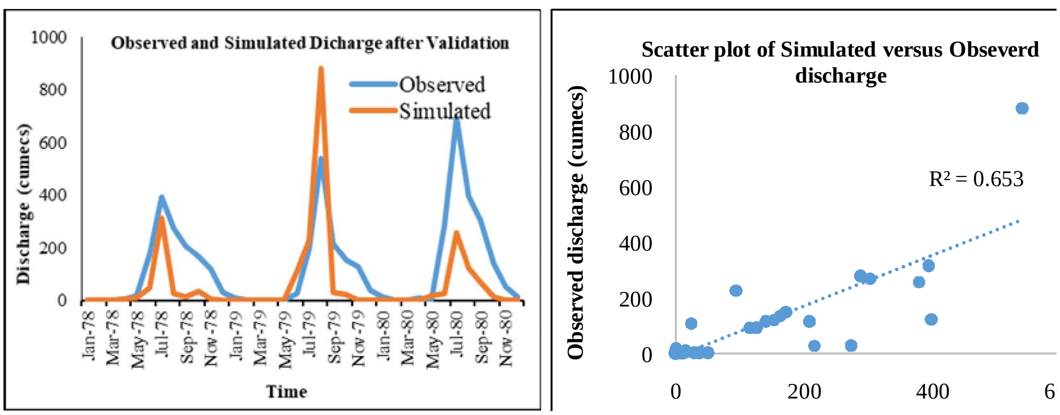

Figure 6: Comparison of the observed discharge with the simulated discharge along with R^2-value after the validation

In Talikot Watershed

The calibration of the SWAT model in Talikot watershed was carried out for 9-years from 1997-2005 to compare the simulated results with the observed discharge. The initial two years were utilized as warm-up period for the SWAT model to avoid the effects of the unknown initial conditions. To calibrate the SWAT model, the parameter was chosen based on the literature review to bring the closeness in discharge curve by comparing simulated results with observed discharge value by determining the R^2 and NSE values. Hence, the model performances after the calibration, R^2, and NSE values were 0.90 and 0.52, respectively, as shown in Figure 7. The validation had performed for 3-years from the period of 2002-2005. The R^2 and NSE are obtained as 0.836 and 0.77, respectively, as shown in Figure 8.

Based on the graphical representation of the observed and the simulated results of the SWAT models, the coefficient of determination R^2 and NSE (Nash-Sutcliffe efficiency) were determined and presented in Table 3. It shows the performance evaluation of SWAT model. The coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) value obtained after the calibration and validation of models indicate that the SWAT model gives very good model performance during calibration, and good at the validation.

Sensitivity Parameters Using the SWAT CUP

The hydrological response varies by varying the range of sensitivity parameters, and the hydrological response also changes, giving different values of R^2 and NSE during the calibration. Six sensitive parameters such as Curve Number (CN-2), Groundwater Delay (GW_DEALY), Base flow (ALPHA_BF), ground water Revap (GW_REVAP), Threshold depth of water (GWQM), and ESCO were considered the most dominating parameters for the Marol watershed. Whereas in the Talikot watershed, the Curve Number (CN-2), Groundwater Delay (GW_DEALY), Base flow (ALPHA_BF), and Threshold depth of water (GWQM) were acted as more sensitive parameters highly affecting the hydrological results of flow in the Krishna basin. These sensitive parameters were determined by using the SUFI-2 algorithm in the SWAT model, as presented in Table 4. It had been found that the curve number (CN_2) affected the runoff hydrograph like when the value increases, the runoff increases. Similarly, the GW_DELAY also influenced the flow values. After adjusting the above sensitive parameters and repeated the simulation for each change, the final R^2 value of 0.872 and 0.90 were obtained. It had been observed that the performance of the model was very good for the Marol and Talikot watersheds.

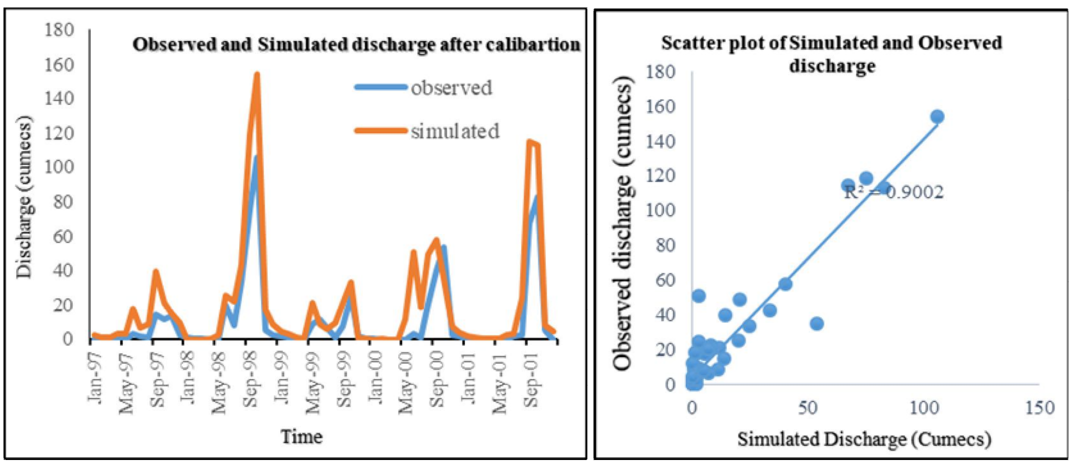

Figure 7: Comparisons of the observed with the simulated discharge along with the R^2 value after the calibration in Talikot watershed

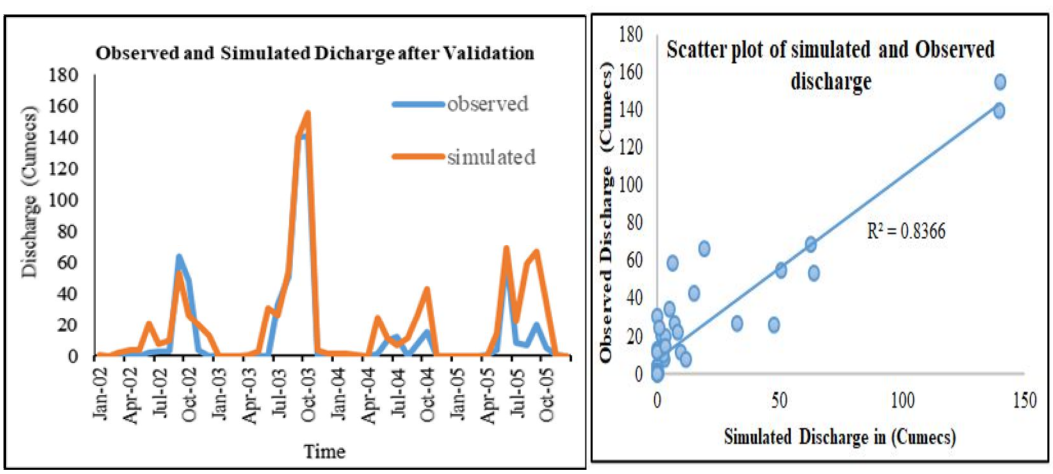

Figure 8: Comparison of the observed discharge with the simulated discharge along with R^2-value after the validation in Talikot watershed

Table 3: Performance evaluation of the SWAT models for Marol and Talikot watersheds, Krishna basin

Sl. No.	Watershed	Calibration Years	R^2	NSE	Validation Years	R^2	NSE
1	Marol Watershed	1971-1977	0.87	0.84	1978-1980	0.65	0.58
2	Talikot watershed	1997-2001	0.90	0.52	2002-2005	0.83	0.74

Table 4: Sensitive parameters for Marol and Talikot watersheds, Krishna basin, Maharashtra

Sl. No.	Parameter	Fitted value	Minimum value	Maximum value
In Marol watershed				
1	CN_2	0.1800	-0.200	0.20
2	ALPHA_BF	0.71	0.00	1.00
3	GW_DELAY	210.599	30.00	450.00
4	GWQMN	0.8600	0.00	2.00
5	GW_REVAP	0.03	0.00	1.00
6	ESCO	0.55	0.00	1.00
In Talikot watershed				
1	CN_2	-0.0733	-0.200	0.20
2	ALPHA_BF	0.683	0.00	1.00
3	GW_DELAY	51.000	30.00	450.00
4	GWQMN	1.233	0.00	2.00

CONCLUSIONS

In this study, an attempt has been made to determine the dominating hydrological parameters for diverse hydro-meteorological watersheds, namely Marol and Talikot micro-watersheds, in Krishna basin with the help of SWAT and SWAT-CUP models. The SWAT model is used to delineate the watersheds located in the diverse hydro-climatic conditions with the unregulated flow in the basin. Further, the extension tool SWAT-CUP model is used to determine the sensitive parameters in these micro-watersheds, and also utilized for the model calibration and validation. The results obtained from the SWAT-CUP after the calibration and validation identified six-parameters such as the Curve Number (CN_2), Groundwater Delay (GW_DEALY), Base flow (ALPHA_BF), ground water Revap (GW_REVAP), Threshold depth of water (GWQM), and ESCO, are more sensitive parameters in the Marol watershed. At the same time, the Curve Number (CN_2), Groundwater Delay (GW_DEALY), Base flow (ALPHA_BF), and Threshold depth of water (GWQM) are more sensitive in the Talikot watershed. They are influencing the run-off in both the watersheds in the Krishna basin. Further the degrees of uncertainty are determined as GW_DELAY.gw >a_CN2.mgt >r_GWQMN.sol for the Marol watershed, and similarly for the Talikot watershed, it is determined as GW_DELAY.gw >r_GWQMN.sol >a_CN_2.mgt. These parameters will help the decision-makers for the sustainable management of water resources in both the micro-watersheds in Krishna basin.

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