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Hydrological Simulation of a Pancheshwer Basin using SWAT CUP Model

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ABSTRACT: For the Pancheshwer basin (13659.45 km^2), which is located on the international border between India and Nepal, a semi-distributed hydrological model, soil and water assessment tool (SWAT) was used to predict the water balance. For this study, the entire basin was divided into six sub basins. Unique slope, soil, and land cover classes are created using the SWAT model. The model was calibrated using monthly discharge data (1982-1986). The goodness-of-fit statistics from parameter sensitivity analysis help focus the calibration and validation analysis. Finally, a study was conducted to determine the seasonal and annual water balance of the Pancheshwer basin for the years 1982-1986. The results demonstrate that the SWAT model can be successfully implemented in the Pancheshwer Basin.

KEY WORDS: Hydrological modeling; SWAT model; Pancheshwer basin; Temperature; Rainfall

I. INTRODUCTION

The total water contained in the hydrological cycle in various forms remains more or less constant; however, per capita water availability is rapidly decreasing around the world due to growing population and rising living standards, resulting in increased demands. This, in turn, necessitates making the best use of available water resources. Despite having made remarkable progress in the development of water resources since independence, India is currently facing several challenging issues in the water sector, primarily due to meteorological factors such as extreme climatic variations and rapid population growth, urbanization, and industrialization. Any significant changes in the water budget will substantially impact hydrologic processes and, as a result, the country's economy and population welfare.Water resource models represent physical, environmental, economic, and social processes to provide insight into potential solutions to water resource problems. For the last four decades, researchers worldwide have been developing empirical or conceptual hydrological models to predict hydrological variables. Simulation models, in which processes are simulated to test alternative scenarios, and optimization models, in which objectives are specified, and parameters are adjusted to meet the goals, are examples of physically-based models. Many water resource models work around a problem's spatial aspects by simplifying assumptions and parameterization (Walsh, 1993). The Soil and Water Assessment Tools (SWAT) model, for example, is a continuous-time model that can operate on a daily time step. The primary goal of model development was to predict the impact of management on runoff, sediment, and agricultural chemical yields over extended periods in large un-gauged basins. Several researchers have tested the SWAT model for runoff and sediment yield daily, monthly, and annual basis (Srinivasan et al. 1993; Srinivasan and Arnold, 1994; Rosenthal et al., 1995). The parameter sensitivity analysis aids in the focus of the calibration and uncertainty analyses, as well as providing statistics for goodness-of-fit. For

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calibration and uncertainty analysis, the programme SUFI-2 was used.

The current study aimed to calibrate, validate, and evaluate the SWAT CUP model using sensitivity analysis for analyzing the water balance components under Indian conditions in the Pancheshwer basin in India. The model was calibrated using observed monthly discharges from 1982 to 1986. Statistical parameters such as the coefficient of determination, Nash-Sutcliffe Coefficient, Index of Agreement, Modified Forms of Nash-Sutcliffe Coefficient and Index of Agreement, Percent Bias, and RMSE-Observations Standard Deviation Ratio were used to assess the model's robustness. Satisfactory model performance criteria indicate adequate calibration and validation. For sensitivity analysis, the SUFI-2 algorithm was used.

II. STUDY AREA

The Pancheshwer basin is the subject of the study. It is located between 29° 07' 30" and 29° 48' North latitude and 79° 55' and 80° 35' East longitude, sandwiched between India's Uttarakhand state and Nepal. The elevation of the area varies between 144 and 7799 m above mean sea level (MSL). The basin is comprised of the Indian districts of Pithoragarh, Bageshwar, Almora, and Champawat, as well as the Nepalese districts of Baitadi and Dharchula. The Pancheshwer basin has a total drainage area of 12,100 km^2, of which approximately 9,720 km^2 is in India and the remaining 2,380 km^2 is in Nepal. Annual precipitation in the basin ranges between 1000 and 2000 mm, with approximately 75% of total precipitation falling during the monsoon months of June to September. July and August are typically the wettest months. The basin's annual average precipitation is estimated to be around 1,620 mm. Typically, the winter season begins in October and lasts until February. Summer begins in March and lasts until the end of May. The total working population in the area is 49.5 percent, while the total dependent population or non-workers in the villages is 50.5 percent (Pre-Feasibility report, 2015). The study area's soil is dominated by clay loam (42.44%), glacial loam (8.81%), loam (9.46%), and silty loam (39.29%), covering an area of 5796.59 km^2, 1203.43 km^2, 1292.38 km^2, and 5366.99 km^2, respectively.

III. METHODOLOGY

When the model prediction is compared to the observed data, model calibration is performed. While changing model input parameter values, the process is repeated to find acceptable prediction model output based on measured data. The following are the manual calibration steps:
(1) The simulation is performed, (2) measured and simulated values are compared, (3)acceptable outcomes are evaluated, (4) if no reasonable results are obtained, input parameters are adjusted within acceptable parameter value ranges based on expert opinion, and (5) the process is repeated until the best results are thought to have been obtained.

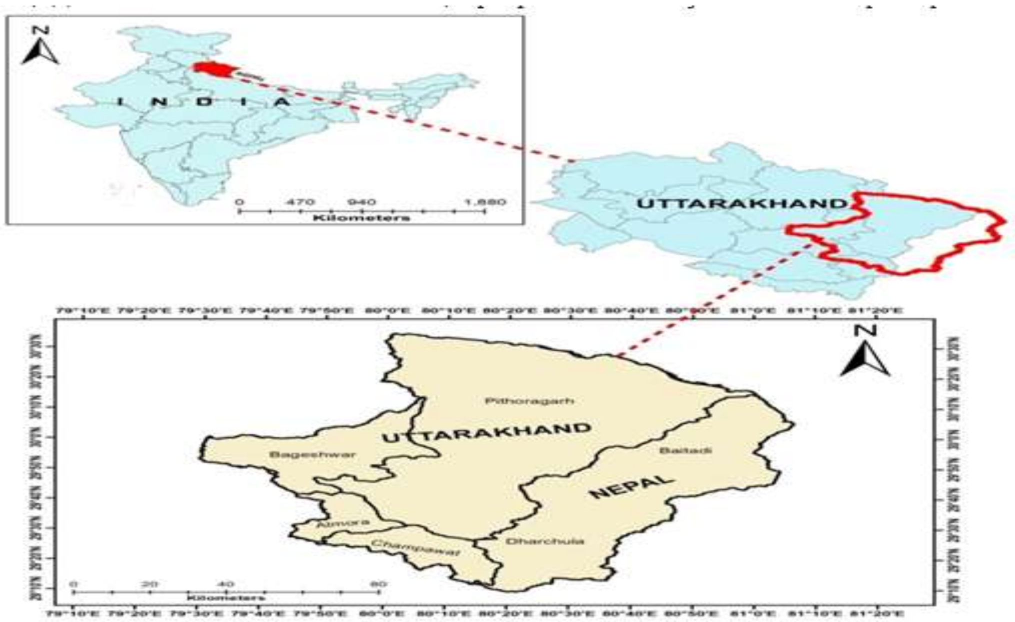

Figure 1: Location map of the Study area

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SWAT-CUP provides a decision-making framework that includes a semi-automated approach (SUFI2) that incorporates both manual and automated calibration as well as sensitivity and uncertainty analysis. The SUFI-2 was used in the model calibration and validation process.

SUFI-2 Running Procedures in SWAT-CUP

SWAT-CUP implements the SUFI-2 calibration methodology by utilizing a large number of system files (exe) for ease of use. In a stochastic calibration approach, these 95PPUs are the model outputs. It's important to remember that we're dealing with an envelope of good solutions generated by specific parameter ranges rather than a single signal representing model output.

The first step in SUFI-2 is to use Latin Hypercube Sampling (LHS), a statistical method for reducing the number of samples from multi-dimensional distributions. SUFI-2 make input.exe is used to place each parameter set in par val.txt into the model in order. The input files par inf.txt, observed.txt, par val.txt, and var file name.txt are used for the best simulation. SUFI-2 goal fn.exe is used to find the best parameters and simulation number. Finally, SUFI-2 95ppu.exe uses par inf.txt, observed.txt, and var file rch.txt to find values for objective functions. The uncertainty values, p-factor, and r-factor, as well as R2, NS, bR2, MSE, and SSQR, representing the best simulation of the current iteration, are all included in the Summary stat.txt file.

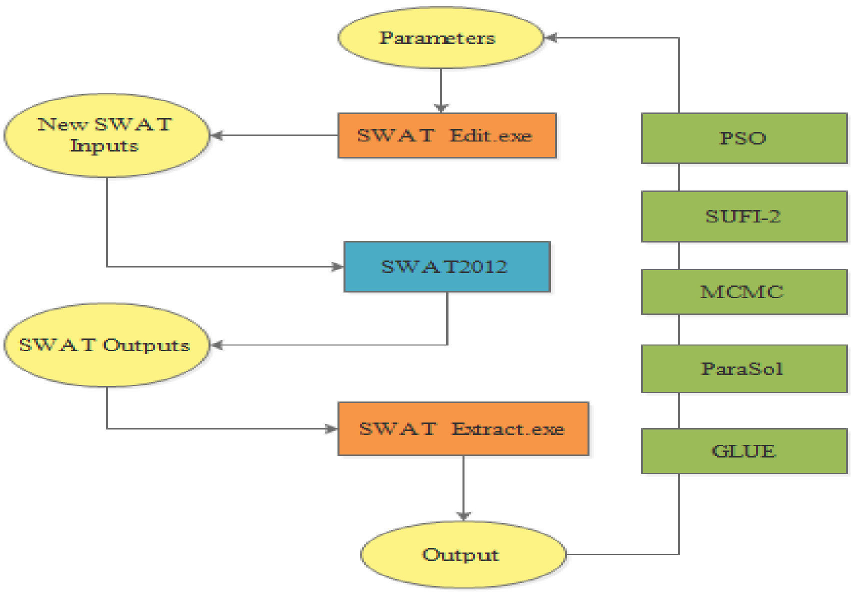

Figure 2: Overall programmed structure of SWAT-CUP

The details of the collection of metrological, hydrological, and satellite data are briefly discussed:

a) Hydrological Data

The discharge data were obtained from the Pancheshwer Dam project's pre-feasibility report in 2015. For the years 1962 to 1992, monthly discharge data were available. The SWAT hydrological model was calibrated using daily discharge data from 1982 to 1985 and validated using discharge data from 1986 to 1992.

b) Meteorological Data

Global Weather Data was used to collect long-term (1979-2014) daily data on various meteorological parameters (relative humidity, temperature, rainfall recorded data, wind speed) for SWAT.

c) Satellite Data

The DEM, Soil as well as land use data sets were re-projected to a common projection system (WGS_1984_UTM_ZONE_44N).

d) Topography

The topography of the basin was estimated using Advanced Spaceborne Thermal Emission and Reflection (ASTER) elevation data in this study.

e) Land use map

The cloud-free digital LANDSAT (TM) data with 30m×30m spatial resolution, which covers the study area, was downloaded by the Global Land Cover Facility site. Satellite data of the autumn

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season (March) for the year 1990 was used to generate the land use/cover map of the Pancheshwer basin.

f) Soil Data

SWAT can represent soil's physical and chemical properties as a soil database. The texture of the soil, the length of the soil layer from the surface to the bottom, the moist bulk density, the available water capacity of the soil layer, saturated hydraulic conductivity, soil erodibility (K) factor, and so on are all physical characteristics of the soil. Soil chemical properties are used to determine the primary values of chemicals present in the soil.

IV. RESULTS AND DISCUSSION

Sub basin and HRU Definition

The Pancheshwer basin's minimum and maximum elevations were determined to be 144 m and 7799 m, respectively, with a mean value of 3971.5 m. The study area was divided into six sub-basins (Figure 3) by strategically selecting outlet points that included observed discharge data in order to facilitate model calibration and validation. Each sub-basin boundary denotes the end of a reach, the point at which all upstream flow data is accumulated and fed into the downstream sub-basin and reach. Once flow lines are established, the model determines HRUs by utilizing additional physical layers. The model defined these distinct hydrological response units. The model's initial run generated 434 HRUs.

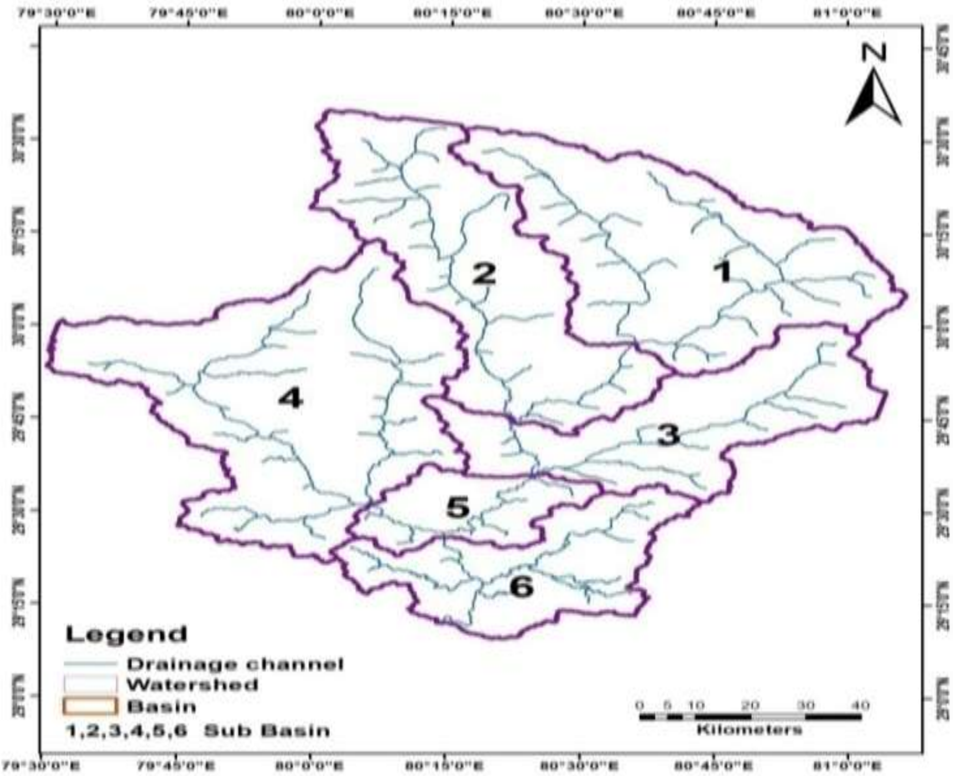

Figure 3: Delineated Sub-basin of the Pancheshwar basin

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Model Calibration

Calibration is the process of changing or adjusting model parameters within recommended ranges to get the model output to match the observed data. The calibration provides the user with several different parameters to adjust. These parameters can be tweaked manually or automatically until the model output is the most accurate match for the observed data. SWAT-CUP was used to calibrate the outlet streamflow in this study. SWAT simulates water balance in daily time steps, with monthly runoff data from 1982 to 1986 used for calibration. The first three years of the modeling period (1979–1981) were set aside for "model warm-up," which involved establishing the states of the model's internal hydrological components, such as groundwater storage, soil moisture content, and so on, in a realistic manner. For selected reaches, changes to the SWAT parameters affecting hydrology were made in a distributed fashion. Parameters were modified by replacing and multiplying a relative change, depending on the nature of the parameter. However, no parameter was allowed to exceed the predefined absolute parameter ranges during calibration. As a result, the model can be used to conduct further research.

Parameters used for Model Calibration

The calibration procedure entailed manually adjusting the SWAT model parameters using a trial-and-error approach until an acceptable simulation was achieved. SCS curve number, plant uptake compensation factor, soil evaporation compensation factor, base-flow alpha factor, groundwater delay time, effective hydraulic conductivity in main channel alluvium, Manning's "n" value for the main channel, and surface runoff lag coefficient were used as input variables for model calibration. Table 5.1 shows the default model value and calibrated values used in the SWAT model and the parameters used for model calibration.

Table 1: Sensitive parameters with their Range and fitted range of values

Sl. No.	Parameter	Fitted Value	Minimum Value	Maximum Value
1	CN	0.16	-0.2	2.0
2	EPCO	0.10	0	1
3	ESCO	0.13	0	1
4	Alpha_bf	0.10	0	1
5	GW_Delay	39.45	30	450
6	GWQMN	261.25	0	500
7	CH_N_2	0.08	0	0.1
8	SOL_AWC	0.03	0	1
9	REVAPMN	71.25	0	500
10	GW_REVAP	0.04	0	0.1

Simulation of Discharge using Calibrated SWAT Model

Different graphs were compared at the sub basin outlets for observed monthly stream flow data to stream flow data simulated by the SWAT model (outlet no. 6). Figure 5.4 shows that the simulated discharge peak values for 1982 and 1985 generally match the observed discharge closely, albeit at different magnitudes. Except for the months with extreme storm events and hydrologic conditions, the monthly predictions were generally good for the simulation period (Rosenthal et al., 1995; Borah and Bera, 2004; Gassman et al., 2007; Borah et al., 2007). This could be due to (1) overestimating early monsoon base flow and (2) a slightly lower CN assignment. In general, the observed discharge was lower than the simulated discharge during the initial phase of monsoon rains. In general, high-intensity rainfall occurs between August and September, and the soil is already saturated in most cases, resulting in high discharge.

On the other hand, if high-intensity rainfall occurs after a few days of dry spells, the model may overestimate the discharge, resulting in

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unsaturated soil conditions. Nonetheless, for well-distributed rainfall events, the model predicted discharge is found to be close to observed values. Another reason for the lower discharge prediction could be the lower density of meteorological stations (data) at higher altitudes, where higher discharge is generally expected. Climate data, understandably, is the most important forcing data for a hydrological model (Hattermann et al., 2005).

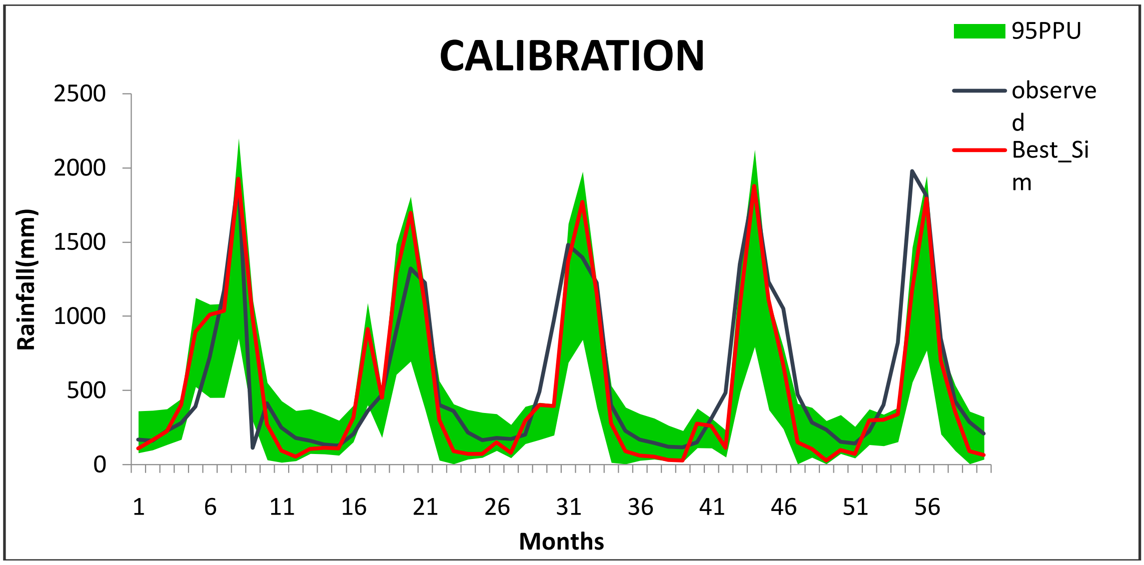

Figure no. 4: Observed and simulated discharge (Calibrated) for the years 1982-1986

Figure 5 depicts the observed and simulated monthly discharges for the calibration period, along with a 1:1 line. The simulated discharge values are distributed uniformly around the 1:1 line for lower values of observed discharge, as shown in the figure. The simulated values for high observed discharge values are slightly below the 1:1 line, indicating that the model under-predicts high discharge values.

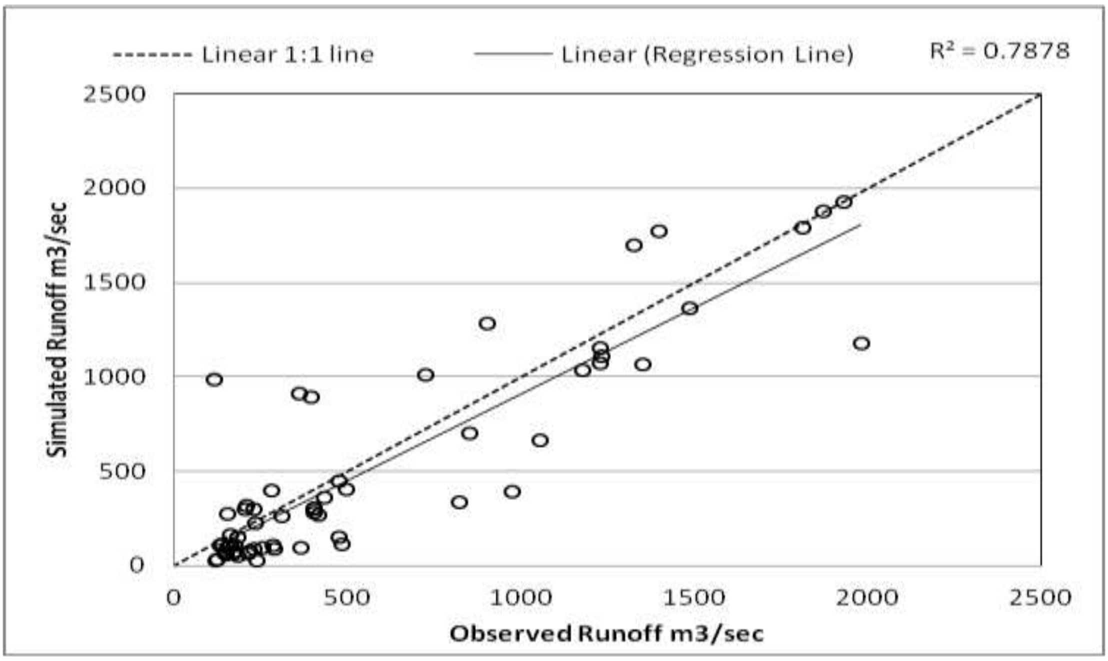

Figure 5: Comparison between the observed and simulated discharge for the years 1982-1986 for model calibration

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Table 2: Statistical analysis of observed and simulated monthly discharge (calibrated) for the years 1982-1986

Statistical parameters	Discharge from Jan-1982 to Dec-1986 (m^3/sec)	
	Observed	Simulated
Mean	569.5	515.3
Standard deviation	533.11	550.95
Maximum	1979	1926
Count	60	60
Coefficient of determination	0.79	
Nash-Sutcliffe efficiency	0.76	
Index of agreement	0.94	
Modified form of Nash-Sutcliffe coefficient	0.55	
Modified form of Index of agreement	0.85	
Percent bias	9.52	
RMSE-observations Standard deviation Ratio	0.49	
Erel	-0.45	
drel	0.64	

The Nash-Sutcliffe model efficiency of 0.76 indicates that the observed and simulated discharges were in good agreement during the calibration period. The range of Index of agreement, Modified forms of Nash-Sutcliffe coefficient (E), and Modified forms of Index of agreement (d1) is similar to that of R2, and is found to be 0.937, 0.55, and 0.85, respectively, between 0 (no correlation) and 1 (perfect fit). PBIAS has an optimal value of 0.0, and low magnitude values indicate accurate model simulation. Positive values indicate underestimation bias in the model, while negative values indicate overestimation bias in the model (Gupta et al., 1999). PBIAS was found to have a value of 9.52. PBIAS value of 9.52 is rated as "very good" for model calibration according to (Van Liew et al. 2007) criterion. RSR can range from a negative value to a large positive value. The RSR is inversely proportional to the RMSE, and the lower the RSR, the better the model simulation performance (Krause et al., 2005). Following calibration, the RSR value was discovered to be 0.494, which is considered a "good rating." As a result, the results show that the SWAT model's overall monthly discharge prediction during the calibration period was satisfactory, and thus accepted for further analysis.

Sensitivity and Uncertainty Analysis

It was possible to determine which variables needed to be precisely estimated in order to make accurate predictions of watershed yields using sensitivity analysis.

In SUFI-2, input parameter uncertainty is represented by a uniform distribution, while model uncertainty is measured at the 95PPU. The p-factor and r-factor are two statistics used to compare the 95PPU band to a discharge. The percentage of measured data (plus its error) bracketed by the 95PPU band is the p-factor. These measurements are within our model's simulation uncertainty, so they are well simulated and accounted for, and the r-factor is the ratio of the average thickness of the 95PPU band to the standard deviation of the corresponding measured variable. A perfect model simulation considering uncertainty with a p-factor of 1 and an r-factor of zero corresponds exactly to the measured data (Abbaspour et al., 2015). According to SUFI-2, the p-factor for the Study area is 0.73 and the r-factor is 0.59.

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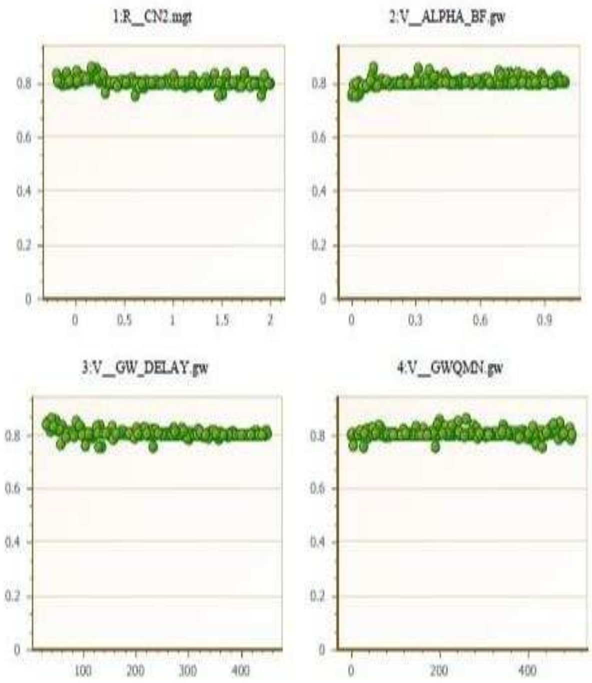
Table 3 Global Sensitive parameters and their ranking for Pancheshwar basin

Sensitivity Rank	Parameter Name	t-Stat	P-Value
1	R__CN2.mgt	-5.53	0.00
2	V__ALPHA_BF.gw	5.49	0.00
3	V__GW_DELAY.gw	-5.07	0.00
4	V__GWQMN.gw	1.40	0.16
5	R__ESCO.hru	-0.70	0.48
6	R__EPCO.hru	0.62	0.54
7	R__GW_REVAP.gw	-0.99	0.33
8	R__REVAPMN.gw	-0.26	0.79
9	R__SOL_AWC(..).sol	0.58	0.56
10	R__CH_N2.rte	0.37	0.71

Global Sensitive
SWAT-CUP provides two types of sensitivity analysis; one-at-a time sensitivity analysis and global sensitivity analysis.

Dotted plots
Dot plots show the distribution of sampling points as well as parameter sensitivity by plotting parameter values or relative changes versus objective function. Figure 6 depicts dot plots for the ten sensitive parameters.



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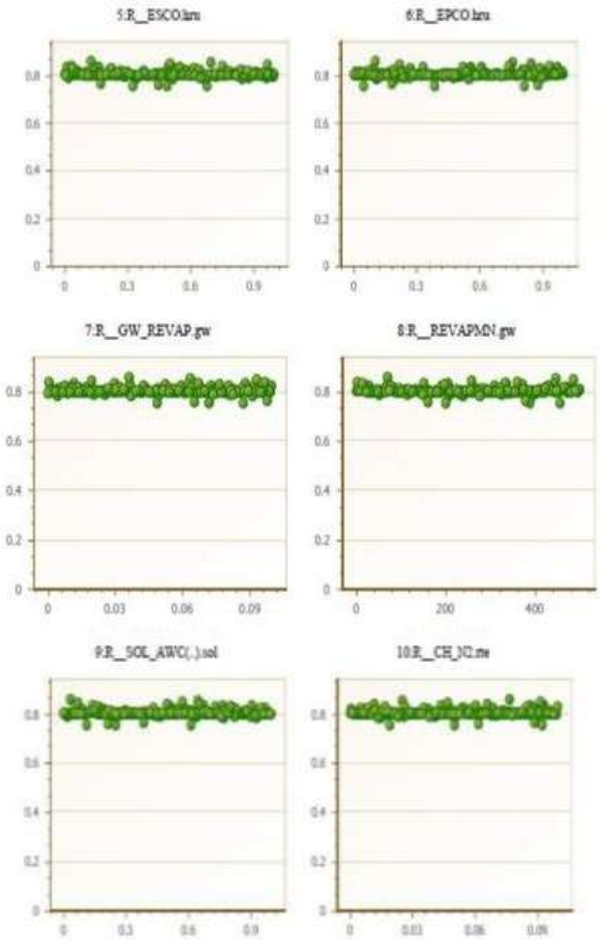

Figure 6: Dotty plots for sensitivity analysis of the basin

Dotty plots were used to demonstrate the sensitivity of the model parameters used for SWAT figure 6 calibration. When a parameter has a sharp and clear peak, it can be considered the parameter with the highest likelihood. Similarly, the insensitive parameters were determined using a diffused peak represented by cumulative distributions, indicating that the parameter was less capable of predicting discharge in the Pancheshwer basin.

V. CONCLUSIONS

The study yielded the following conclusions:
Rainfall patterns are erratic, posing a risk of abnormal flooding in the Pancheshwer basin.
1. For the Pancheshwer Basin, the most sensitive parameters were CN, available water capacity, soil depth, soil evaporation compensation factor, and shallow aquifer water threshold depth (GWQ MN).
2. For monthly simulation, the Mean, Standard deviation, and Maximum values were 569.5, 533.11, and 1179, respectively, during model calibration, and simulated monthly discharge (calibrated) values are 515.3, 550.95, and 1926, indicating satisfactory performance. The SWAT model can be used to evaluate the hydrology of the Pancheshwer basin based on these findings.
3. Dotty plots were used to demonstrate the sensitivity of model parameters used in SWAT calibration. When a parameter has a sharp and distinct peak, it can be considered the parameter with the highest likelihood. In the same way, the insensitive parameters were obtained using a diffused peak represented by cumulative distributions, indicating that the parameter was less skilled in predicting discharge in the Pancheshwer basin.
4. The HRU water balance analysis allows for the spatial identification of areas where management practices to improve water use could be suggested. The Pancheshwer basin's minimum and maximum elevations were discovered to be 144 and 7799 m, respectively, with a mean value of 3971 m.
5. By increasing basin use management, appropriate measures like strip cropping and vegetative filter strips can reduce run-off. This

means that the study area, the Pancheshwer basin, is relatively underutilized in terms of water resource development and utilization.

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