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Original Article

Calibration of Shetrunji River Basin Using SUFI-2 Algorithm in SWATCUP

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Abstract *- Modern times have found a way to overcome the laborious and time-consuming manual methods of performing modelling on physically based models. This work is also a depiction of such a method that incorporates the automatic calibration technique using "SWATCUP (Soil Water Assessment Tools Calibration Uncertainties Program)" which is available in the public domain. This work is a later part of the hydrological modelling, which was done in ArcGIS and interfaced with SWAT 2012. Out of many programs available, one of the most renowned algorithms known as SUFI-2 (Sequential Uncertainty Fitting version 2) is used for the calibration. The demonstration is done on one of the major tributaries of Western India famously known as Shetrunji River, Gujarat, India. The model calibration was carried out from 2012 to 2015 on a monthly basis using the observed data fetched from local government agencies and IMD (Indian Meteorological Department). With numerous permutations and combinations of trials, the results obtained are found to be pretty promising. The co-relations obtained from the trials show satisfactory outcomes with an* R^2 *value of 0.81 and an NSE (Nash Sutcliffe Efficiency) of 0.79. The study can further be taken to other watersheds having similar features.*

Keywords *- SUFI-2, SWATCUP, Calibration, Validation, Nash Sutcliffe Efficiency.*

1. Introduction

A watershed model is crucial for researching how land use and climate change affect water resources. Understanding the watersheds' biological, hydrological, and other processes allows for the prediction of land surface area characteristics due to the significance of spatial variability[1]. As the social economy is flourishing day by day, the orientation towards spatial data acquisition has been continuously enhancing like RADAR, Remote sensing, Navigation and GIS (Geographic information systems) [2]. GIS is an effective tool for watershed modelling. For the study purpose, various distributed hydrological models are being widely used, such as SWAT, IHDM, TOPMODEL, etc., from which the SWAT model, designed by the United States Department of Agriculture based on Arc GIS software, is the most emerging model for simulating watershed application [3]. A wide range of hydrological models employ the SWAT. With the help of the SWAT model, analysis of hydrological characteristics, soil change characteristics and transfer of chemical pollutants and sediment in a basin can be carried out as it treats different data as the input and reflects the outcome of human activities and climate change to the runoff characteristics of the basin[3]. This simulation can be realized in the areas that are lacking in data[4]. Different models have been applied to streamflow simulation in various world regions [5]. Using Geographic Information System software (ArcGIS 10.3), a hydrological and basin-scale model was integrated to create SWAT, a hydrological model that can accurately determine the basin's ecological response[6]. Due to their integration through cycle, storage, and agricultural patterns, the hydrologic cycle and surface and subsurface processes of the earth are closely related. Therefore, the study of runoff above and below the earth's surface using scientific methodologies and approaches is necessary to detect environmental problems in terms of land use/land cover changes, soil degradation, climatic changes, and their impacts on ecosystem services [7].

Additionally, engineering design, flood forecasts, global water balances, navigation, reservoir operations, water supply, recreation, river design, irrigation planning, agricultural practices, and environmental management all depend on understanding the water flow rate [1]. In order to plan the sustainable application of water resources to meet multiple demands, hydrological models are crucial tools. The possible effects of anticipated changes in climate and water resource management can be illustrated using a hydrological model [8]. The interaction of water supplies, environmental factors, hydropower, and natural hazards is known as a hydrological cycle. A hydrological model, which can provide accurate answers to numerous issues, is strongly advised in order to determine the effects of changes in population, land use/cover, and climate [9]. Models must be precisely stated in order to comply with the current modelling mindset, and modelling efforts typically include sensitivity, validation, calibration, and uncertainty analysis [10].

Model calibration is the act of modifying a generalised model to better accurately depict the conditions and processes unique to a certain site. Running a model using parameters that were decided upon during the calibration phase on a data set that isn't utilised for calibration is the process known as validation. Whether the model accurately replicates the real system or not, validation needs to be done to increase trust.

One can perform manual calibration or use automatic calibration tools such as SWAT-CUP [11]. User experience in modelling and recognizing parameters are the two main significant skills to achieve success in manual calibration. On the other hand, automatic calibration requires input files to be filled out only once [12]. SWAT-CUP is a generic interface and stand-alone program developed for SWAT model calibration [13]. Researchers have developed and employed a variety of models, including empirical, lumped, and distributed models, to simulate the streamflow at the catchment outlet in relation to rainfall and snowmelt [14]. The research and feedback cited above demonstrate that the SWAT model has been successfully used in the modelling and computation of water resources and hydrologic process characteristics.

Moreover, the SUFI-2 approach and the SWAT-CUP were used to validate and calibrate the SWAT model by yielding adequate results. Thus, the objectives of this study are as follows: 1) To test the feasibility and capability of the SWAT-CUP with SUFI-2 algorithm for runoff simulation of the study area, which will contribute to the preservation of natural resources in the Shetrunji watershed and thereby is useful for sustainable development. 2) To assess the most sensitivity parameter and 3) To examine the uncertainty of hydrologic parameters in arid and semi-arid environments, as well as the effectiveness of the SWAT model in estimating and modelling runoff.

2. Study Area

In Saurashtra (Gujarat, India) Shetrunji River basin is one of the most vulnerable Rivers in accordance with climate change. This river rises in the Chachai Hills and travels eastward until it meets the Gulf of Khambhat close to the port of Santrampur [15]. The fetch length of this river is 227 km, with a catchment of 5646 km^2. The average annual rainfall is 673.15mm. There are two major dams namely Khodiyar and Shetrunji, situated on the river at 55 km and 160 km length from the inlet. It provides water to Amreli, Bhavnagar and Junagadh for agriculture. The research region has a tropical and subtropical climate, with January having the lowest mean monthly temperature of 14.5°C to 20°C and May having the highest maximum monthly temperature of 30°C to 44°C. In the lower Shetrunji River basin, this investigation is being carried out.

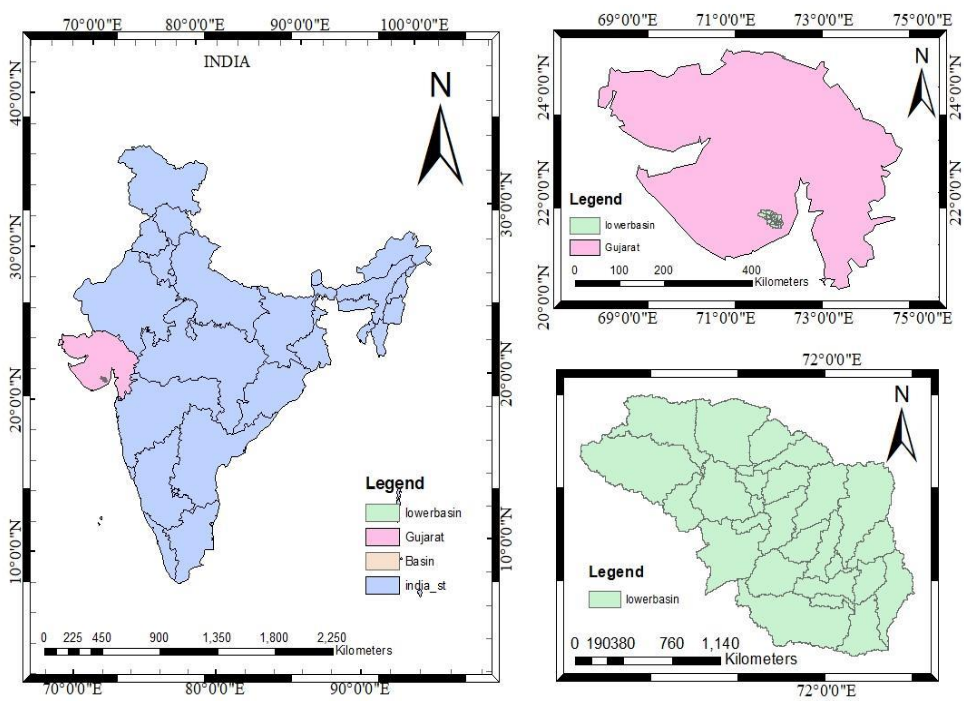


Fig. 1 Study area map: Shetrunji River, Gujarat, India

3. Methods

The calibrated model can behave according to the inputs provided, and this behavior can be used to understand the properties of the actual watershed and the vulnerability (if any) in accordance with the climatic parameters [16]. The SWAT Calibration Uncertainties Program, or SWAT-CUP, was created to examine the forecast uncertainty of the calibration and validation outcomes of the SWAT model. The SWAT-CUP can integrate various calibration/uncertainty analysis procedures for SWAT in one user interface. It is a public domain program that links Sequential Uncertainty Fitting ver.2 (SUFI-2), Particle Swarm Optimization (PSO), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), and Markov Chain Monte Carlo (MCMC) algorithms to SWAT model. Scholars worldwide have effectively employed this model for watershed modelling and resource management in watersheds with diverse climatic and topographical features. For streamflow, sediment, and other environmental reasons, the SWAT model requires calibration of numerous input parameters [17].The process of calibration in this study starts with the installation of the SWAT-CUP tool, which is available in the public domain. The basic requirement of this tool is the output folder of the SWAT run project, as shown in Figure 2. After successfully incorporating the project folder and files, the tool will enable the functions on the left panel, as shown in Figure 3.

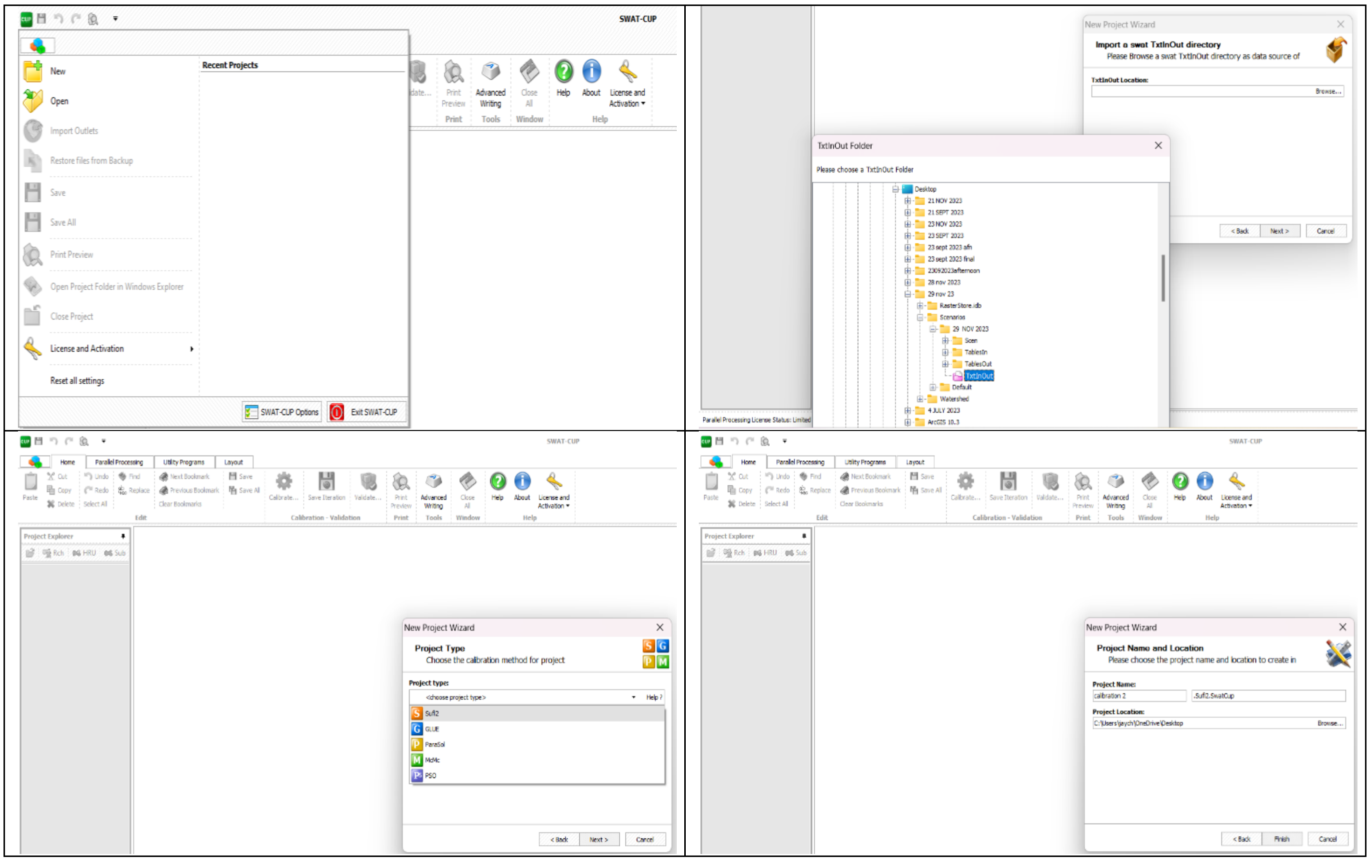


Fig. 2 SWAT-CUP step: Selection of SWAT output folder

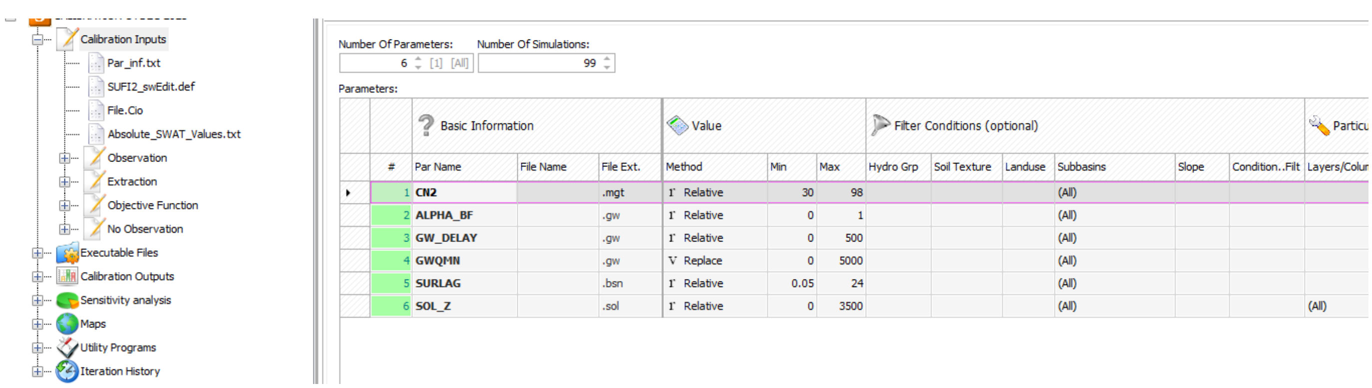


Fig. 3 SWAT-CUP step: Activation of SWAT output folder

3.1. Sensitivity Analysis

The first and most important step now is the selection of the sensitive parameters of the variables, which may vary based on the type of work pursued. For the sensitivity analysis, the 'Latine Hypercube Sampling- One at a Time' method is used to determine the sensitivity of each parameter. In this study, 19 different sensitive parameters with the upper and lower bound were selected for sensitivity analysis based on the extensive literature review and data analysis as illustrated in Table 1. The selected most sensitive parameters are shown in Figure 3. Following the steps shown below, the calibration process is run.

Table 1. Sensitivity analysis of parameters

No.	Input Parameter	Description of Parameter	Min and Max Range
1	CN2.mgt	SCS runoff curve number	30 – 98
2	ALPHA_BNK.rte	Base flow alpha factor for bank storage	0 - 1
3	ALPHA_BF.gw	Baseflow alpha factor (days)	0 – 1
4	GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0 - 5000
5	SURLAG.bsn	Surface runoff lag time (days)	0.05 – 24
6	GW_DELAY.gw	Groundwater delay (days)	0 - 500
7	SOL_Z.sol	Depth from soil surface to bottom of layer (mm)	0 to 3500
8	GW_REVAP.gw	Groundwater "revap" coefficient	0.02-0.2
9	SOL_AWC.sol	Available water capacity of the soil layer (mm H2O /mm soil)	0-1
10	SOL_K.sol	Saturated hydraulic conductivity(mm/hour)	0 to 2000
11	SOL_BD.sol	Moist bulk density (g/cm3 @ Mg/m3)	0.9 to 2.5
12	CH_K2.rte	Effective hydraulic conductivity in main channel alluvium (mm/hr)	0.025 to 250
13	EPCO.bsn	Soil evaporation compensation factor	0 - 1
14	CH_N2.rte	Manning's 'n' value for the main channel	0.13-0.67
15	OV_N.hru	Manning's "n" value for overland flow	0.01 - 30
16	SL_SUBBSN.hru	Average slope length (m)	10-150
17	HRU_SLP.hru	Average slope steepness (fraction)	0-1
18	RCHARG_DP.gw	Deep aquifer percolation fraction	0 - 1
19	REVAP_MN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0 - 500

3.2. Calibration Inputs

The regression starts with the step (*Par_inf.txt*) that shows the list of sensitive parameters with their properties and range, as shown in Figure 4, followed by the number of simulations represented as *SUFI2_SWEdit.def*as shown in Figure 5. The number of trials strictly depends upon the complexity of the problem. Then comes the step, namely *File.cio, which shows the gener*al information about the project description, date, time, number of years for simulation and many more, which can be seen in Figure 6 along with the neighbor step named *Absolute_SWAT_values.txt* that involves no addition from the user (Figure 7).

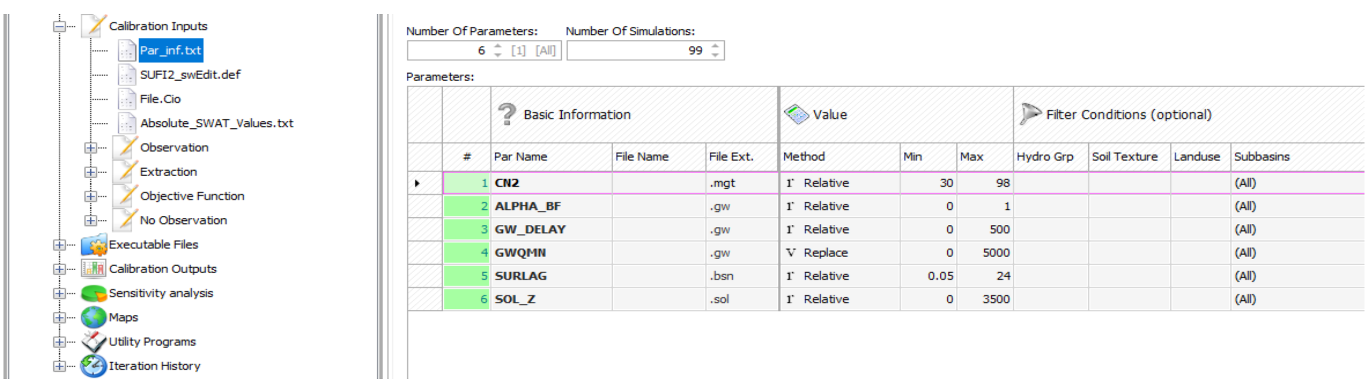


Fig. 4 Step showing calibration inputs-Par_inf.txt

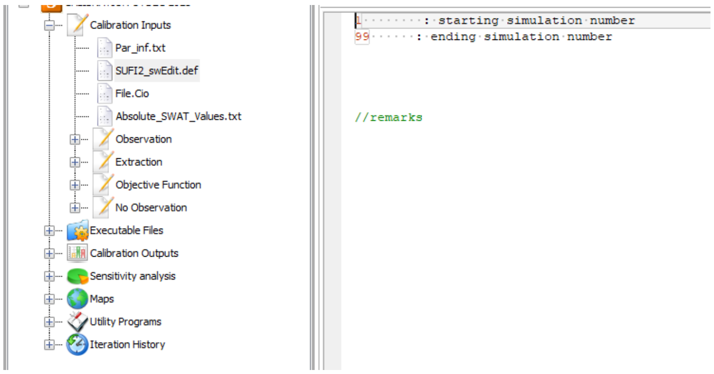


Fig. 5 Step showing calibration inputs-SUFI2_SWEdit.def

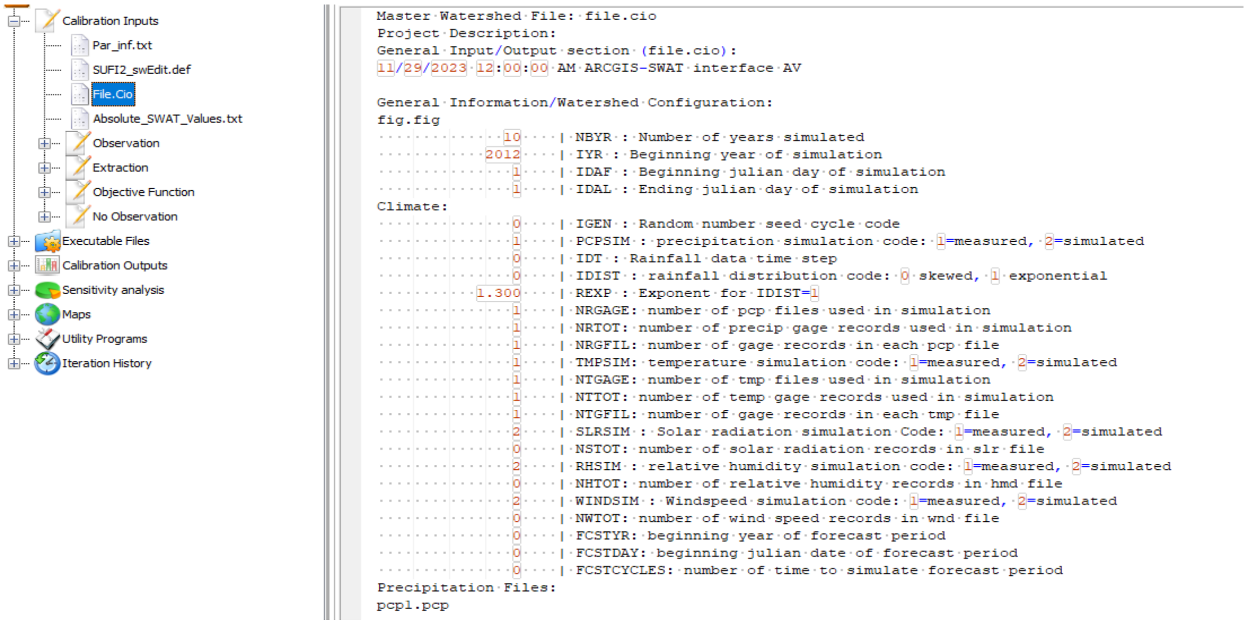


Fig. 6 Step showing calibration inputs-File.cio

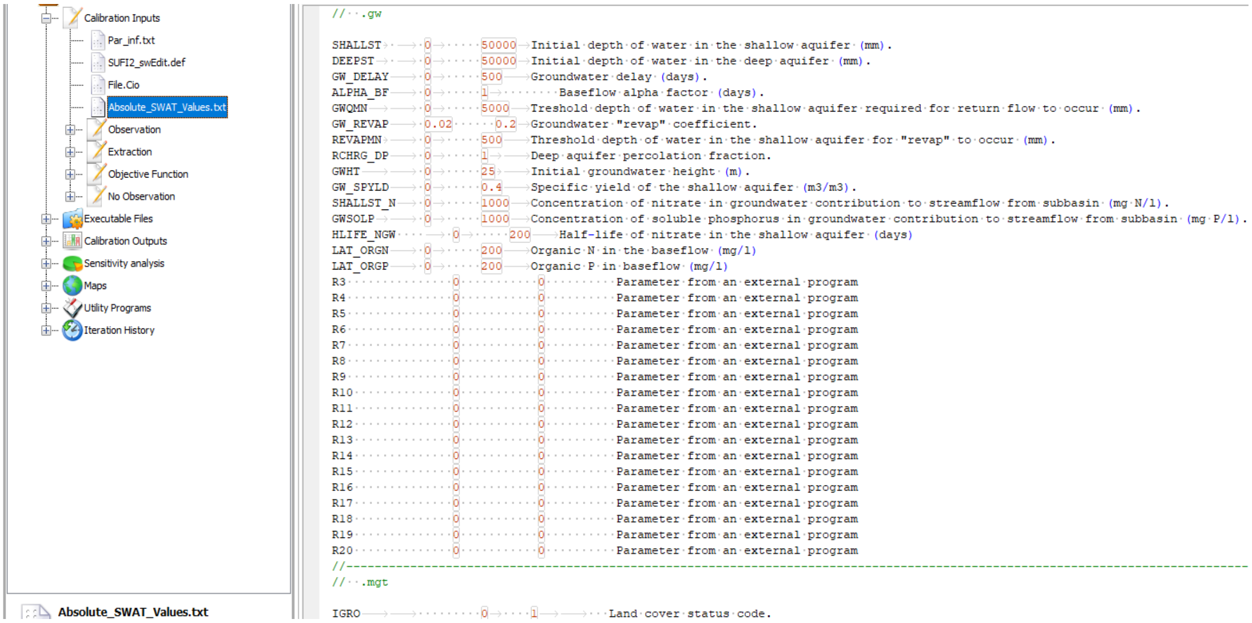


Fig. 7 Step showing calibration inputs-Absolute_SWAT_values.txt

3.3. Observation

This step, called *Observed_rch.txt* includes the incorporation of the variable that happens to be discharged in this study, along with the number of sub-basins. Also, the frequency of the outputs (Annual/Monthly/Daily/Sub daily) and the observed values are to be shown here in Figure 8.

This is followed by the selection of the outlet, which is significantly important to synchronise the observed data and the modelled data.

In this study, sub-basin number 28 is chosen (Figure 9) for the process, as the observed data is collected from the same source.

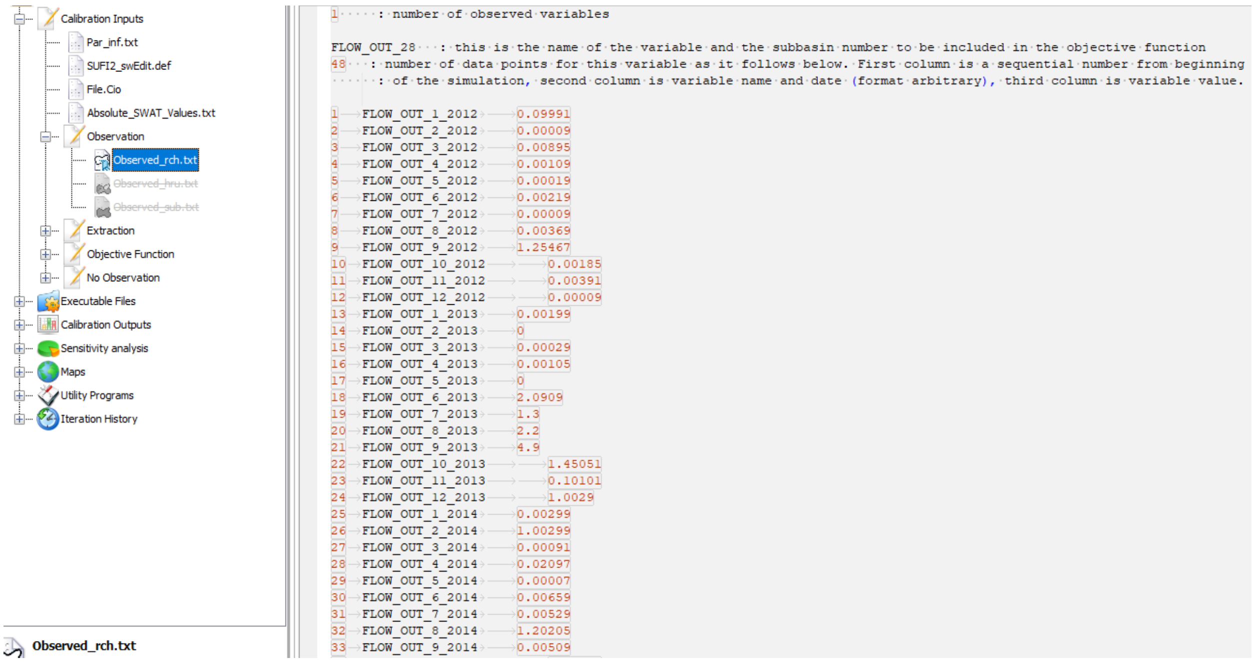


Fig. 8 Step showing Observation - Observed_rch.txt

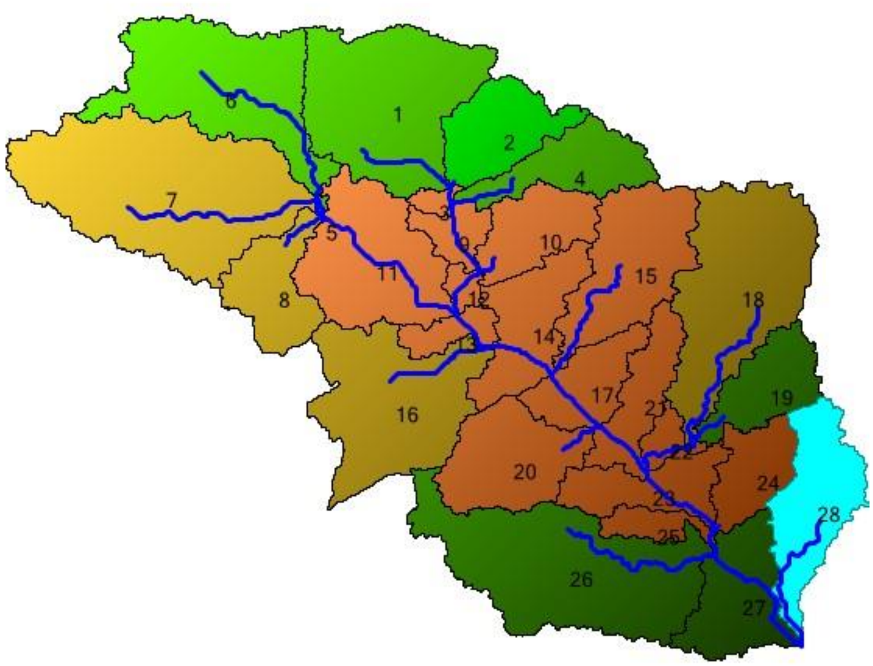


Fig. 9 Selection of subbasin-28 for calibration

3.4. Extraction

This module consists of two sub-modules, namely *Var_file_rch.txt* and *SUFI2_extract_rch.def*, that provides the addition of the name of the variable followed by the number of sub-basin (FLOW_OUT_28.txt) and the selection of respective column number from SWAT output respectively as shown in figure 10. Also, the beginning and end years of the simulation are to be added in the later step (Figure 11).

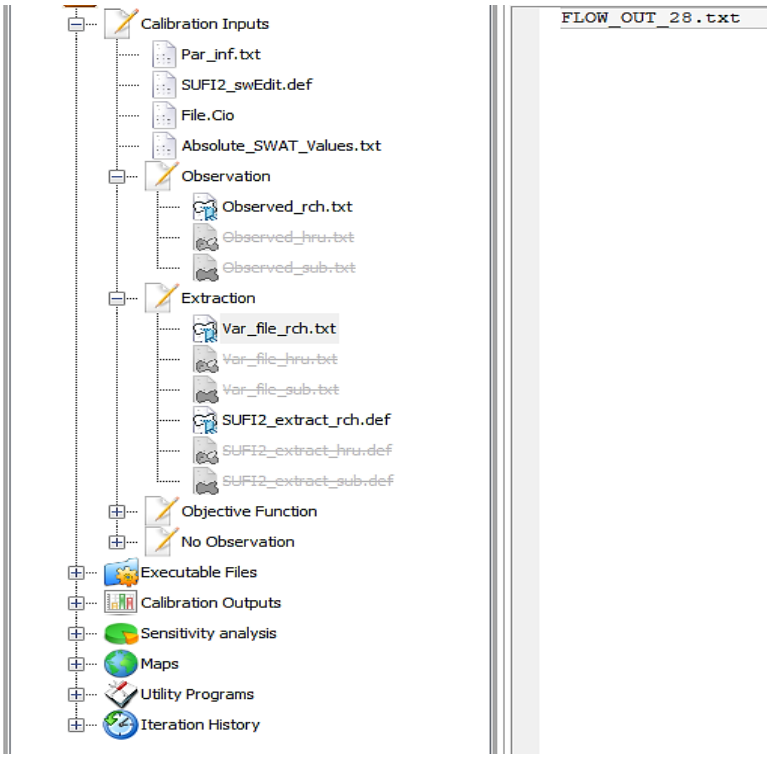


Fig. 10 Step showing Extraction-Var_file_rch.txt

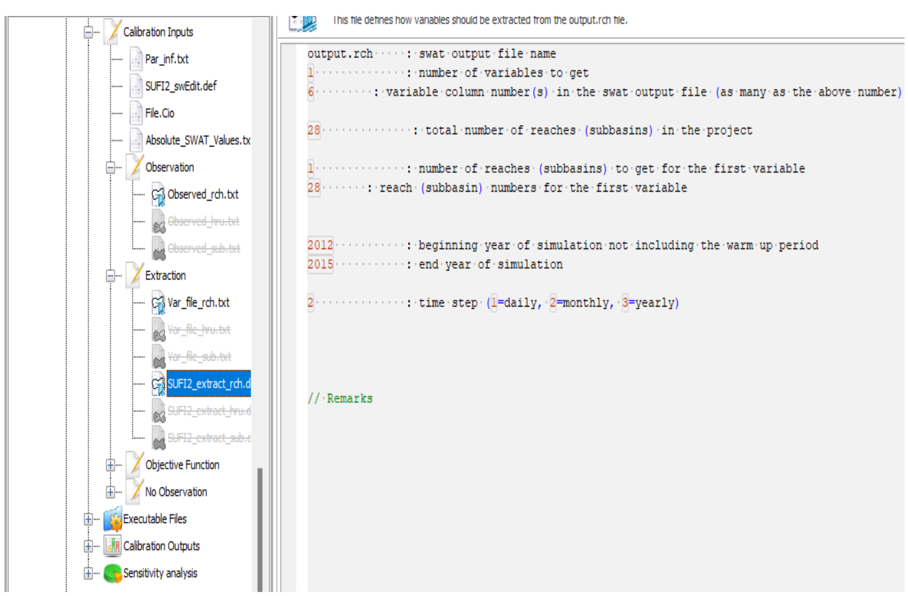


Fig. 11 Step showing Extraction - SUFI2_extract_rch.def

3.5. Objective Function

This, being the last active part of the input process, is divided into two steps, namely *Observed_txt* and *Var_file_name.txt*. It includes adding the correlation parameters from different available parameters and the program that shows the prompt window in cmd format to provide the affirmation to the calibration run, as shown in Figures 12-14.

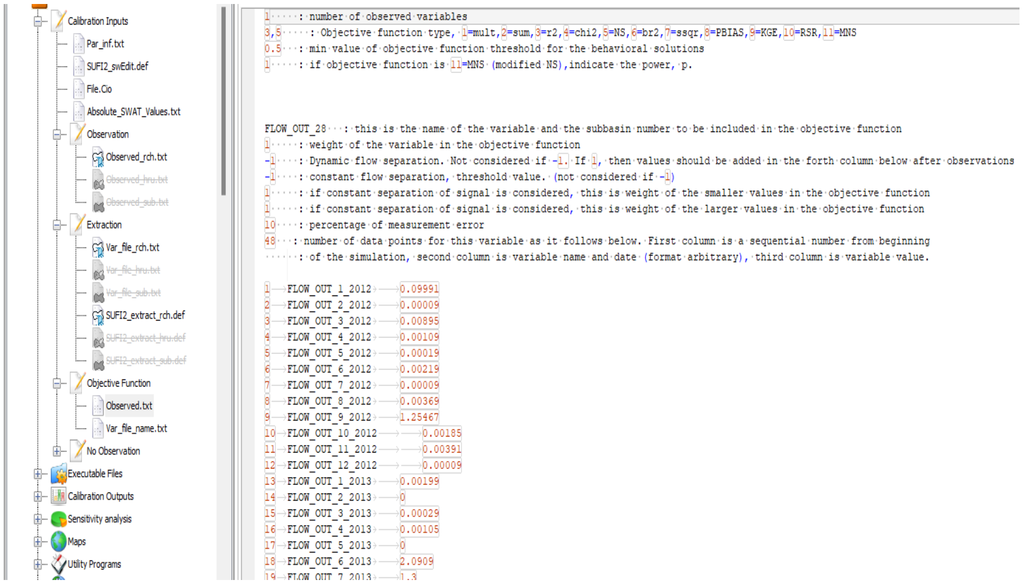


Fig. 12 Step showing Objective Function - Observed_txt

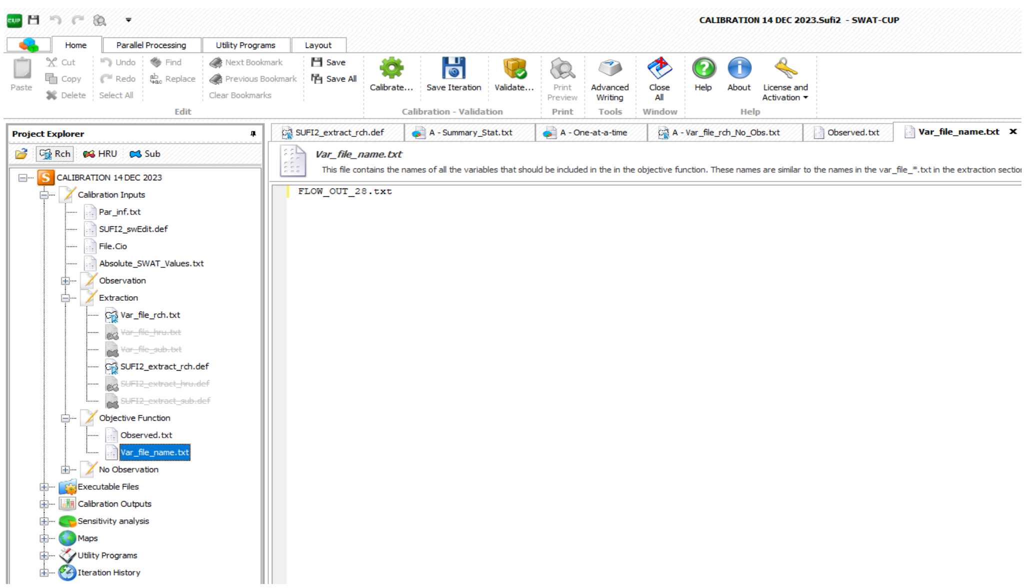


Fig. 13 Step showing Objective Function - Var_file_name.txt.

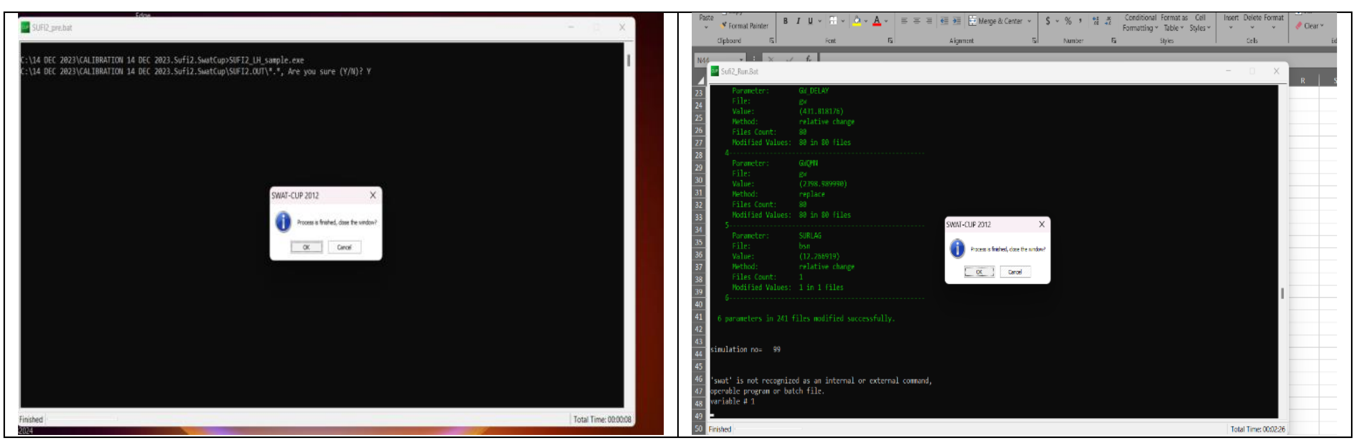


Fig. 14 SWAT-CUP step to provide access to the calibration run

4. Results & Discussions

The calibration process is significantly important to authenticate the outputs of the models. Likewise, the process of sensitivity analysis plays an important role in refining the calibration process. In this project, the sensitive parameters are being classified based on their vulnerability and the level of impact that they create on the outputs. This is followed by the ranking of the sensitive parameters, also called as variables, which is done based on the literature review and the threshold values as the model shows the variations in the outputs. The final ranks and the sensitive parameters are shown in Figure 15.

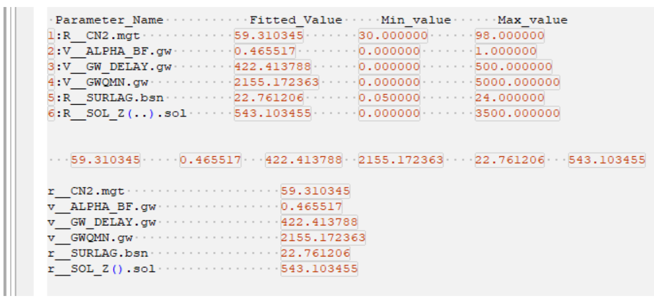


Fig. 15 Final ranks and the sensitive parameters

The highly underrated and one of the most dynamic tools, namely SWATCUP, is made to run the calibration trials, as shown in Figure 2. As is seen in Figure 3, out of five modules required to be run, it takes numerous number of trials to minimize the turbulences between the observed values and the modelled outputs. The model's efficiency is determined by correlations like NSE, RSR, bR^2, R^2 and PBIAS, as shown in Figure 16. Whereas for this study purpose, R^2 is given the prime importance, followed by NSE. The NSE (Nash & Sutcliffe 1970) was computed using an equation.

$$\mathrm{NSE} = 1 - \frac{\sum_{t=1}^{T}(Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_o^t - \overline{Q}_m)^2} \qquad (1)$$

Where Q_o is the mean of observed discharge, and Q_m is modelled discharge. Q_o^t is the observed discharge at time t. NSE can range from - ∞ to 1. An efficiency of 1(NSE=1) corresponds to a perfect match of modelled discharge to the observed discharge data. An efficiency of 0 (NSE=0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (NSE <0) indicates that the observed mean is a better predictor than the model.

Fig. 16 Result showing co-relations

The coefficient of determination(R^2) was computed using the following equation.

$$R^2 = 1 - \frac{SS_{rest}}{SS_{tot}} \qquad (2)$$

Where SS_{tot} is the total sum of squares and SS_{rest} is the sum of squares of residuals. This is also done by the recommendations of the researchers who have been through this process.

After several permutations and combinations, the tool was able to optimize the outputs, giving the value of R^2 as 0.81 and NSE as 0.79, as shown in Figure 16. Also, the final results showing the observed values and modelled values are shown in Figure 17.

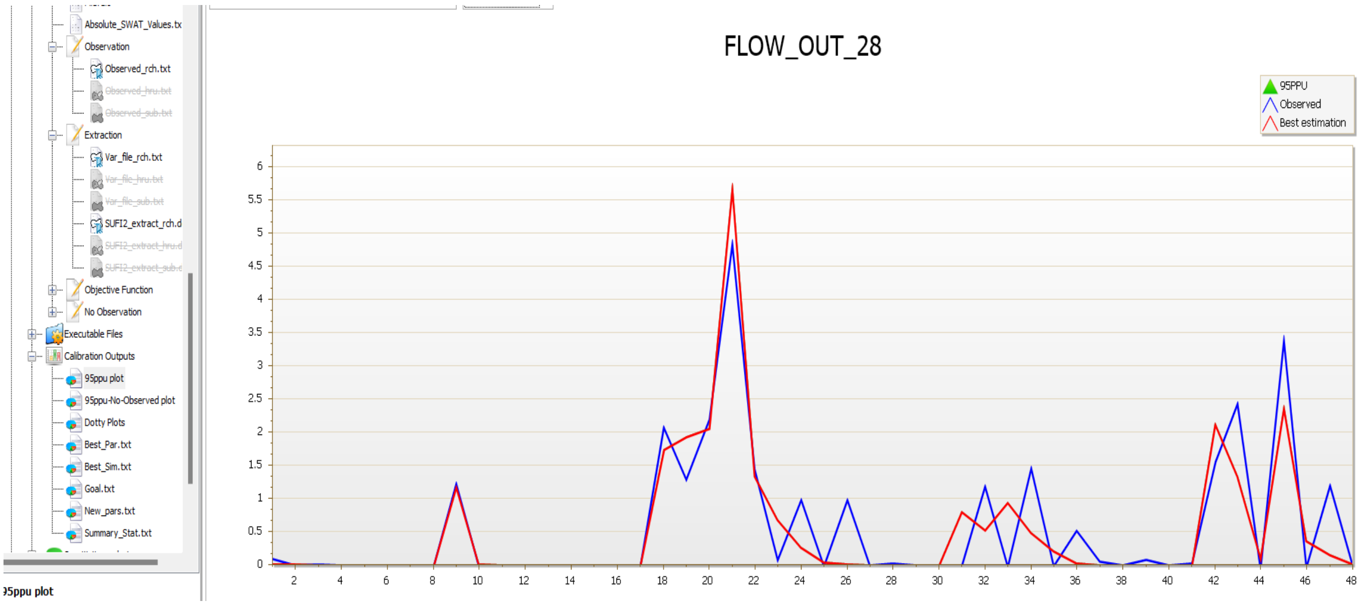
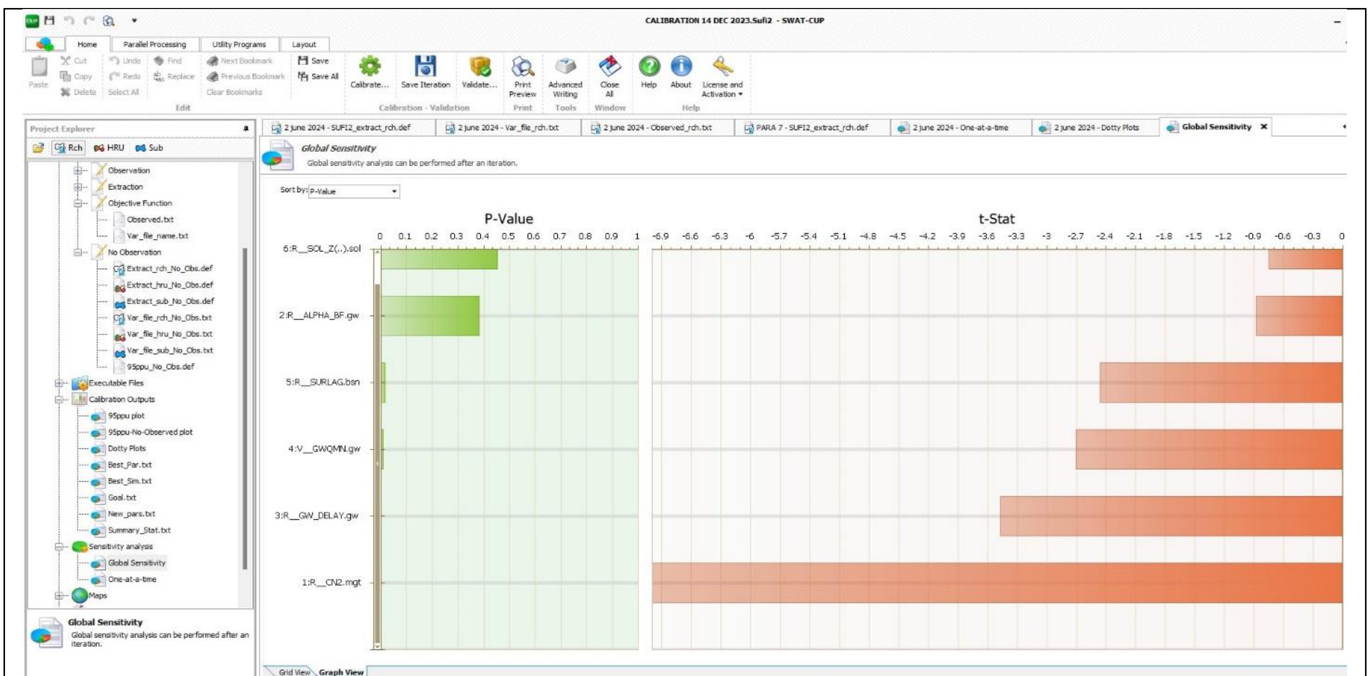


Fig. 17 Final results Showing the observed values and modelled values

Figure 18 shows the values of the correlation factors, namely *P- value* and *t -value*, *which* clearly portray the reasonable classification of the sensitive parameters along with their rankings.



Parameter Name	t-Stat	P-Value
6:R__SOL_Z(..).sol	-0.751625856	0.454194609
2:R__ALPHA_BF.gw	-0.878838105	0.381778670
5:R__SURLAG.bsn	-2.463060047	0.015636041
4:V__GWQMN.gw	-2.702016724	0.008206550
3:R__GW_DELAY.gw	-3.472532960	0.000787547
1:R__CN2.mgt	-6.995528376	0.000000000

Fig. 18 Values of the correlation factors P- value and t -value

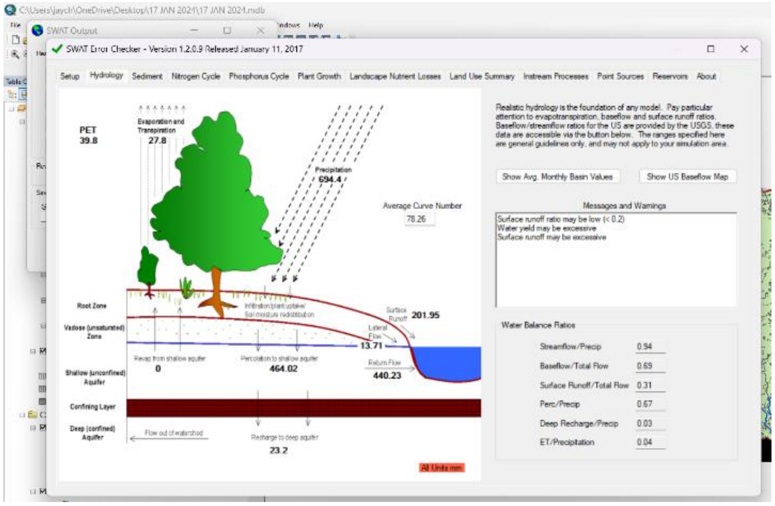


Fig. 19 Final results of SWAT after calibration

The final determined values of the chosen sensitive parameters are incorporated into the SWAT model, which was uncalibrated, and the results are shown in Figure 19.

5. Conclusion

In the present society, where the growth and development in technology are increasing exponentially, it has become critically important to authenticate the quality of the products supplied. The same applies to modelling, where the number of models is available, which provides the results round the clock instantaneously. But the problem here is the efficiency of the outputs that they provide. To overcome this, the researchers have introduced calibration techniques, which help the researchers to minimise the anomalies between the actual (observed) outputs and the modelled outputs. The present work is a demonstration of the technique used to calibrate the SWAT model that was prepared for the Shetrunji River basin. The procedure to perform the calibration on the hydrological model SWAT is explained in depth in this work. After determining the number of permutations and combinations, the final layouts of the successful trial are represented here with the help of the screenshots taken during the process. From the results it is depicted that the algorithm named SUFI-2 provides promising results. Global sensitivity analysis was applied to identify flow-sensitive parameters, and the SCS runoff curve number (CN2.mgt) was found to be the most sensitive parameter. The correlation parameters also possess significantly accurate values that justify the uniqueness of the process. Furthermore, this technique can be applied to assessing evapotranspiration's impact on water resources, sedimentation, climate change, water quality, and land use change. This work can further be extended by adding the validation process.

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Author Contributions

Gargi Rajapara: Abstract, Methodology
Zarna Chovatiya: Data Analysis, Writing-Original draft preparation, Software, Validation
Zuned Shaikh: Writing-Reviewing and Editing.

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