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Calibration and Uncertainty of the SWAT Model Using the SUFI-2 Algorithm

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ABSTRACT

In the application of models, less attention is paid to the quantitative determination of the importance of uncertainty that predicts variability and input parameter values. Hydrological models require a lot of input parameters that are not fully known. Because of this uncertainty, the models are not able to accurately describe hydro-logic and chemical processes under normal conditions. In this study, the SWAT model was used to simulate flow in the Maroon Dam basin. The model was implemented for the period 1994-2001. Moreover, uncertainty testing was through using the SUFI program. The results showed that the SWAT model could be a useful tool for simulating river flow intensity. In this investigation we adjust and calibrate an unified hydrological model using the Soil and Water Assessment Tool (SWAT) program. various elements of water resources are simulated and water quality are measured at the Hydrological Response Unit (HRU) level. The water resources are computed at subbasin level with monthly periods. The use of comprehensive, high-resolution water resources models enables steady and inclusive investigation of unified system behavior through physically-based, data-driven simulation. In this investigation we examine issues with data accessibility, calibration of large-scale distributed models, and outline methods for model calibration and uncertainty analysis. The methods technologically advanced are overall and can be practical to any large zone around the universe. Multi-objective hydrological model calibration can indicate a valorous solution to diminish model equifinality and parameter uncertainty. The Soil and Water Assessment Tool (SWAT) model is extensive used to considerate water quality and water management issues in catchment.

Keywords: *Uncertainty - SWAT - Runoff Simulation - SUFI2*

INTRODUCTION

Due to the impact of water resources development, changes in land use and applied management practices in land and water resources on the amount of sediment entering the reservoir dam and the uncertainty of the impact of these activities on sedimentation dams, it is necessary to find the exact procedures and low-cost Estimating the impact of these activities on the extent of catchment erosion is important. Hydrological models are essential instruments for scheduling maintainable apply of water resources to encounter several requests. The present modeling attitude needs that models are clearly described; and that calibration, validation, sensitivity and uncertainty analysis are normally executed as part of modeling exertion.

As calibration is “contingent” (i.e., conditioned on the model structure, model inputs, analyst’s suppositions, calibration algorithm, calibration data, etc.) and not uniquely determined, uncertainty analysis is important to appraise the capability of a calibrated model. The Soil and

Water Assessment Tool (SWAT) (Arnold et al., 1998) has verified its abilities in the statuses specified above. It is an open source code with an extensive and increasing number of model applications in different studies ranging from catchment to continental scales. In the "Hydrologic Unit Model for the United States" (HUMUS), Arnold et al. (1999) applied SWAT to simulate the whole U.S.A. for river discharges at around 6000 gauging stations.

In Iran, due to lack of hydrometric stations in the watersheds, there is a problem with any planning and management planning. In addition, due to the lack of accurate and sufficient statistics on the discharge of the sub-branches of the main rivers, all river operations are based on approximate guesswork. In such a situation, awareness of the watersheds' visions and their hydrological response, and the accurate estimation of the current water level, will reduce costs by reducing the costs of flood management through accurate management. Usually this is done by using various hydrological models that estimate the runoff rate using different theoretical methods. SWAT-CUP (Calibration and Uncertainty Procedures) (Abbaspour et al., 2007) is a independent software advanced for calibration of SWAT. The plan includes five various calibration methods and contains qualities for validation and sensitivity analysis as well as incarnation of the zone of study using Bing Map. With this feature, the subbasins, simulated rivers, and outlet, rainfall, and temperature stations can be incarnated on the Bing map. In the usual task we used the program SUFI-2 (Abbaspour et al., 2004; Abbaspour et al., 2007) for model calibration and uncertainty analysis. For time-spending large-scale models, SUFI-2 was found to be entirely affective (Yang et al., 2008).

The SWAT model used in this project showed a high correlation with observational data in the Miami Creek, Long bridge, and Coulter basins.

As a result, the researchers consider this model to be a high-performance alternative to the large hydrological processes of large scale basins.

On the other hand, because almost all measurements are uncertain, the simulation results of the model are usually presented at the statistical level and the result of the output always requires calibration for uncertainty of the output data. In this study, the SWAT1 program was used to estimate the runoff of the Maroon Dam basin. Various parameters used in the model, such as flow parameters, sedimentation, etc., were determined by using the inverse method and using the SUFI2 program.

Therefore, in this study, the results of the runoff calibration stage simulated by the SWAT1 model in the Maroon Dam catchment (Idenq) were carried out using the observational data of the Adink hydrometric station located at the basin outlet. The presented results are part of the results of model application for providing integrated model of catchment management based on different management scenarios of the basin and their effect on outflow runoff. This paper merely evaluates the accuracy of the model in forecasting runoff of the basin and compares similar values Observations and observations. The consequences from this discussion purvey a steady data package on the quantity and quality of water resources on temporal and spatial dimensions, and on internal renewable water resources.

Area of Study

Maron River originates from the Zagros Mountains, with its area of 2750 km2, at the Hydro Meter Idenq station. The area of the Maroon dam (Adenq) catchment area is 2,750,000 hectares. The basin is located between 50 degrees and 15 minutes to 51 degrees east and 30 degrees 45 minutes to 31 degrees 15 minutes' north latitude. The maximum and minimum height of the basin is 3415 and 360 m, respectively, and the average height of the basin is 1656 m.

Table1-3. *Location of the stations under study*

Name of Station	Type Station	Statistical Period	Height (M)	Northern Latitude	Eastern Longitude
Ednak	Fixed rain gauge	1987-2006	560	**΄ - 57 ˚30**	**΄ - 25 ˚50**
Dehno	Normal rain gauge	1996-2006	1400	**΄ - 59 ˚30**	**΄ - 53 ˚50**
Ednak	Hydrometry	1987-2006	560	**΄ - 56 ˚30**	**΄ - 24 ˚50**

The SWAT software is a general, semi-distributed, continuous-time, processed-based model (Arnold et al., 2012; Neitsch et al., 2005; Gassman et al., 2007). The program can be applied to build models to appraise the effects of intermittent management decisions on water resources. The hydrological component of SWAT permits clear calculation of various water balance components, and latterly water resources at a subbasin level. The SWAT model is a conceptual-semi-distributive model in basin scale that runs at hourly, daily, or longer-term times. The model simulates a large number of spatial sub-divisions by dividing a basin. The main parts of the model include hydrology, climate, erosion, plant growth, nutrient elements, pesticides, land management, and streamlining. In this model, each basin and each sub-area are divided into several "Hydrological Reactor Units" (HRU), which are applied in terms of land and soil characteristics homogeneous. In this case, the water content in the soil, surface runoff, nutrient cycle, sediment, plant growth and management methods are calculated for each hydrological reaction unit and then for each sub-basin as a weighted average.

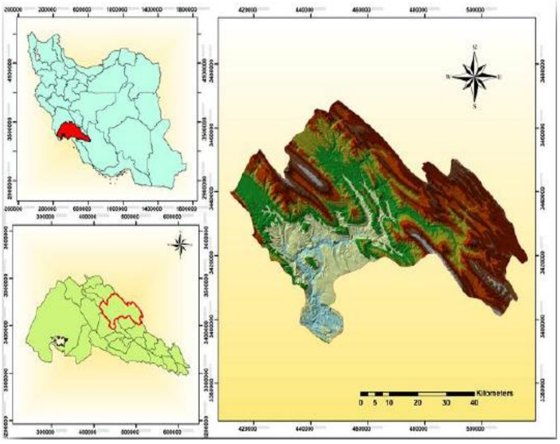

Figure1. *Geographic location of the Maroon dam (Adenq)*

In the SWAT model, firstly, the DEM basin is divided into a number of sub-basins. Then, based on soil maps and land use, sub-basins are divided into smaller units, each of which is called an HRU.

Running the Model

The two important components want to install SWAT softwares are 1. Any GIS program to apply and use of effective maps. 2. A component that can produce all the files required by SWAT. The information needed for SWAT adjusted into two categories: spatial data (DEM, land use map, soil map) and temporal data(air temperature(both minimum and maximum), precipitation, relative humidity, wind speed and solar radiation).In order to achieve better results, the information was carefully prepared and introduced into the model. After completing this information, the model was executed. In order to simulate the basin, after the arrival of information, the slope was run for 1994-2001. In this research, the study area was divided into 23 sub-watersheds (HRUs), and the runoff of the basin was simulated. The results of this simulation are shown in Figures 2 and 3. According to the results of the simulation, simulation results are in line with the observed values of the basin at the Eindak station and show a high correlation coefficient.

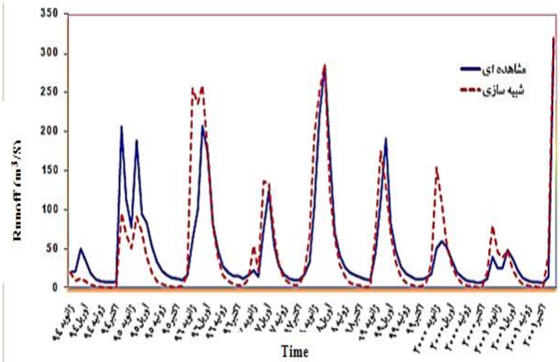

Figure2. *Calibration results of the model at the Aden station*

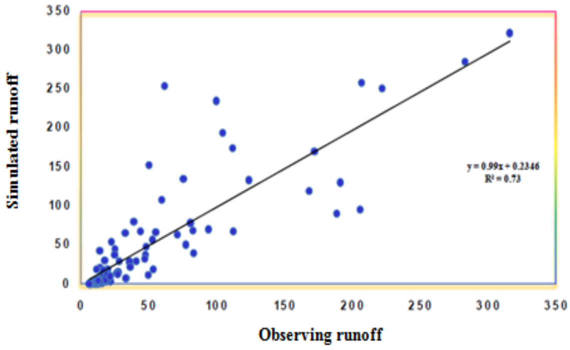

Figure3. *Comparison of observed and simulated runoffs*

Simulated Runoff Uncertainty Estimation

The uncertainty analysis of a model is intended to determine the statistical characteristics of the outputs of that model as a function of the uncertainty of the input parameters. Uncertainty in scientific discussions means a range of changes that can be considered for a parameter. Since only a limited number of measurement data and, on the other hand, physical systems are usually modeled by continuous equations, so there is no inverse hydrological problem that can be solved individually. Also, since all temperature and precipitation distribution correction processes appear only in the measured data (including measurement uncertainty), therefore unmatched data is a model error and uncertainty in the prediction model of the existence model has it.

Due to the physical nature of the model, many parameters are required for its adaptation to the conditions of the region. The SWAT model requires various data to run. Data that requires calibration due to the uncertainties involved. On the other hand, at the calibration stage, it should be possible to modify the model's assumptions with respect to the characteristics of the basin. Calibration of the model was performed to obtain the optimal parameter value by using two versions of software SUFI-2.

In the SUFI-2 program, it is assumed that each unknown parameter is distributed uniformly in a domain with a certain uncertainty. The uncertainty of the output of the model is estimated by the uncertainty of 95%, which is computed at 2.5 and 97.5% of the distribution function of the output variable, which is sampled by a Latin hyperkub sampling method from the domain.

In SUFI-2, the uncertainty for all its sources T is calculated including the uncertainty in the initial variables (including rainfall), the conceptual model of the parameters and measured data. The degree of all uncertainties is determined by measuring the factor p, which is the percentage of the integral part of the measured data with 95% uncertainty (95PPU) in prediction. Since all the processes of correction of temperature and precipitation distributions appear only in the measured data (including measurement uncertainty), there are irreducible data of the model error and, consequently, uncertainty in the model prediction. Therefore, the percentage of data obtained by predicting the lack of importance of evaluation for the ability to analyze is irrelevant. 95SPP is calculated at the distribution levels of the 97-mile series and the second output is obtained, meaning 95% of the very weak simulations is breaking or dividing uncertainty into very interesting and very interesting teachers, and as far as the researcher-researchers are informed. There are still no valid methods available for others. Others reduce grade, calibrate, and analyze the lack of factor that the average thickness of the 95PPU tape is divided by the standard deviation of the measured data. Parameters become so when the new intervals are always smaller than the previous intervals and are centered on the best simulation of the factor. The fit and degree that the calibrated model shows is measured by measuring two factors R and F.

Theoretically, the value of R is the factor between zero and infinity, while P is the equivalent of one that is exactly equivalent to the measured data. The distance from these numbers can determine the degree of calibration power. A larger P factor is obtained when R is a larger factor. When the acceptable values in factor R and factor P are obtained, the uncertainty of the parameters is in the desired range. In addition, fitting accuracy can be finalized by either R2 or the NS coefficient between observation and simulation.

SUFI-2 Program Algorithm in Uncertainty Band Calculations

Because the SUFI process is a stochastic process, statistical parameters such as error rate, K2 and Nash-Sutcliff coefficient, etc., which compare the two variables, cannot be applied. Instead, 95PPU is computed for all variables by 2.5 (X_L) and 97.5 (X_u) percent of the distribution function of each simulated point. The average distance between the upper and lower limits of 95PPU (d) is obtained from the following equation:

$$\bar{d}_x = \frac{1}{k}\sum_{l=1}^{k}(X_U - X_L)_l$$

Where **k** is the number of observation points. The optimal mode is when 100% of the measured points are in the 95PPU region and the $\mathbf{d_x}$ value is close to zero. However, due to measurement errors and uncertainty, the model does not get the right amount. Based on experience, a reasonable relation for estimating **d** is:

$$d - factor = \frac{\bar{d}_X}{\sigma_X}$$

σ_X; The standard deviation of the measured variable is **X**.

Because the uncertainty of the parameters is initially large, the value of **d** in the simulation is large. Therefore, the range of parameters must be closed. The new domain for each parameter is obtained from the following equation:

$$b'_{j,\min} = b_{j,lower} - Max\left(\frac{(b_{j,lower} - b_{j,\min})}{2}, \frac{(b_{j,\max} - b_{j,upper})}{2}\right)$$

$$b'_{j,\max} = b_{j,upper} + Max\left(\frac{(b_{j,lower} - b_{j,\min})}{2}, \frac{(b_{j,\max} - b_{j,upper})}{2}\right)$$

That **b'** is the updated values. In addition to narrowing the range of parameters for each subsequent replication, the criterion ensures that the updated parameter intervals always focus on the best estimates.

Runoff Simulation Results and its Uncertainty Bands

In order to perform calibration, the model of effective parameters in runoff was selected based on previous studies. Then several repetitions are performed to adjust the range of parameters and make a suitable domain as small as possible and close to reality for each parameter. As these parameters play an important role in the output of the model, this large domain must be selected as much as possible. In this study, the SUFI program was used because it is easily linked to the SWAT.

The SUFI program began with the assumption of large parameter uncertainty (large domain selection for each parameter). In order to optimize the model at each stage of its implementation, non-effective parameters of runoff were identified and removed from the list of effective parameters. Finally, 10 important and effective parameters on flow were selected in the basin. Based on the sensitivity analysis, the runoff curve number (CN), soil moisture content (AWC), and alpha-base flow coefficient are among the most sensitive parameters for runoff.

In this study, the probability of data reliability was determined from 92.5% to 97.5% during the calibration, and the desired simulated uncertainty band was determined according to the diagram of Fig. 4 for the Idenq station. Since the station's observation flow chart and simulated band within the band are 95% uncertain, the results of modern output and acceptable error are obtained. The parameters for checking the model simulation accuracy are also given in Table (2).

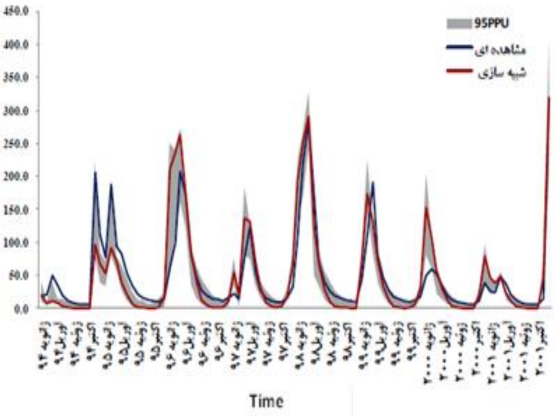

Figure4. *Uncertainty of runoff runoff at the Aden Station*

Table2. *Parameters for the accuracy of simulation of the model*

Station	Number of data	R2 percentage	NS percentage	Factor P	Factor D
Ednak	94	0.73	0.63	0.59	1.05

It should be remonstrated out from the inception that calibration of watershed models is subjective and no automatic calibration algorithm can change the knowledge of the analyst vis-à-vis watershed hydrology and calibration subjects. The calibration results of the model showed an appropriate correlation between simulation of the model and the measured data on the intensity of the flow of the Marun River at the hydrometric station. Referring to Figs.2 and 3, it is shown that the process of model simulation matches the observed values. The results at most points are in good agreement with the measured values. However, it does not fit in between February and May. The reason for this is that the model does not have the ability to simulate the flow of water accurately at the discharge, which is also considered in other researchers' research. For this weakness, a reason is mentioned that one of the most important reasons for this is the weakness of the model in simulating the melting process. This topic is more important in mountainous areas. Due to the mountainousness of the studied area, the reason for the lack of conformity cannot be attributed to the exact simulation of snow melting in the mountains located at the river Sarcheshmeh. Rustamian reported that most of the currents that the model could not simulate were happening in the spring. The SWAT1 model divides rainfall using the average daily temperature in the form of rain or snow. Due to the weakness of the model in the simulation of monthly runoff in the spring, it can be concluded that the model is not able to simulate full melting of snow in mountainous areas and does not simulate the maximum runoff rate. One of the other reasons is the lack of a meteorological station and the lack of representative of the stations used in the model.

Conclusion

Watershed patterns have become a primary tool in addressing a vast spectrum of environmental and water resources obstacles. The model was calibrated for a many numeral of river discharge stations. The model SUFI-2 in SWAT-CUP Tool was applied for calibration/uncertainty analysis, validation, and sensitivity analysis. Only readily available data were applied for model setup further calibration and validation. In this study, Maroon basin simulation relating to Maroon sub-basins was used to evaluate the performance of the SWAT model in the monthly and monthly discharge simulation of a watershed of 2750 km/ m^2 by gathering all information about the area and taking the effective parameters in the hydrologic cycle of the basin into account. The acceptable results were showed in relation to the reality in the region as a result. According to the studies, it can be concluded that the SWAT model was able to simulate the maroon dam basin. Therefore, calibration of runoff from the basin was based on the observation data of the station by the SUFI program, with acceptable error rates. Using this model due to mountainousness, shortage of hydrometric stations, and especially due to the reduction of time needed for analyzing issues, is an appropriate tool for land management to reduce runoff and sediment. Using this model, hydrologists and executives can evaluate various management scenarios in a short time, without having to spend a lot of money, and make the best decision. In conclusion, it is depicted that information the accessible technology on model building and calibration tools, and the accessibility of freely accessible data it is feasible to make a continental model at high spatial and temporal resolution. Better data availability of course, would help to make model predictions more precise and undistincties smaller. If enough numeral of rain gauge stations are accessible, it is essential to use that rainfall data.

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