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An Assessment on Base and Peak Flows Using a Physically-Based Model

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Abstract: A physically-based model namely the Soil Water Assessment Tool (SWAT) was used on the Roodan watershed in southern part of Iran; the watershed has an area of 10570 km^2. The main objectives were to simulate monthly discharge and evaluate the base and peak flows separately. Required parameters to run the model were meteorological data, soil type, land use, management practices and topography maps at watershed scale. To find the sensitive parameters, an initial sensitivity analysis was performed using the Latin Hypercube sampling One-at-A-Time (LH-OAT) method embedded in the SWAT model. Then, the model was calibrated and validated for stream flow using the SWAT-CUP program. Generally, the model was assessed using the modified coefficient of determination (bR^2), Nash-Sutcliffe (NS) and PBIAS. Values of bR^2 and NS were 0.93 and 0.92 for calibration respectively and 0.69 and 0.83, respectively, for validation. For calibration and validation, PBIAS were obtained at 23 and 5%, respectively. Reviewing the results, it seems that simulation of the monthly peak flows has better harmony (fluctuation) than monthly base flows for Roodan watershed. To summarize, the simulated SWAT stream flow was within the acceptable range for Roodan watershed as an arid catchment.

Keywords: Base flow, discharge modeling, peak flow, SWAT-CUP program

INTRODUCTION

These days, the hydrology of arid and semi-arid catchment areas has become an important topic of research and water resource planners have been looking and searching seriously into water resource crisis solutions and erosion for these zones (Foltz, 2002; Dafa-Alla *et al*., 2011). Moreover, sustainable development is important issue clearly (Omer, 2010). Hydrological modeling and surface water resources management are essentially connected to the geographical processes of the hydrologic system. Development of computer science has resulted in better research of hydrologic systems during the past decades (Singh and Frevert, 2006) Therefore, many models have been applied to hydrological modeling and water resources management (Oogatho, 2006). Hydrological model classification is broad, but these [1]conceptual models can be generally classified into three groups, namely lumped, semi-distributed and distributed model (Gosain *et al*., 2009). Among the various types of models, semi-distributed models are the most effective for hydrological simulation as it overcomes the difficulties often encountered with fully distributed model and lumped model. Moreover, researchers develop semi-distributed models as a tradeoff between lumped models and fully distributed models (Arnold *et al*., 1993).

The Soil and Water Assessment Tool (SWAT) model has shown to be a beneficial model program for assessing nonpoint-source pollution problems and water resource at various scales and under different environmental conditions across the world (Arnold *et al*., 1998). It is a type of semi-distributed model that subdivides the watershed into smaller sub-basins and Hydrological Response Units (HRUs) (Leon *et al*., 2002). Semi-distributed model gives better physically-based structure in comparison with lumped model. Moreover, it requires lesser amount of input data in contrast with fully distributed model, which usually requires large amount of data for parameterization. Nevertheless, this also means that the main physical processes are still being processed in detail and therefore can offer the highest degree of accuracy. However, distributed model does have some problems concerning nonlinearity, scale, uniqueness and uncertainty (Beven, 2001).

A comprehensive literatures review on SWAT models around the world has been previously reported by Gassman *et al*. (2007). Recently, SWAT models have also been evaluated in Iran for various purposes because of limited water sources and soil (Mirzaei *et al*., 2011) and a brief literature review had been carried out in this research. We discovered that SWAT model had been used to simulate the main mechanisms in the hydrological cycle and to study the impact of land-use changes for the Zanjanrood basin in Iran (Ghaffari, 2010). An extensive review was also done on the mesh size of digital elevation modeling using

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SWAT to model runoff (Ghaffari *et al*., 2011). The issue of uncertainty that stems from different sources and is shown in the simulated outputs of the SWAT model has been investigated for the Kasilian River (Talebizadeh *et al*., 2010) as well. Some research used the SWAT model to study the water resource management of a large-scale area in Iran where hydrological components like the surface runoff, deep aquifer recharge, soil water and actual evapotranspiration were analyzed (Faramarzi *et al*., 2009). Additionally, a study on water scarcity in Iran due to wheat production had been carried out too using SWAT (Faramarzi *et al*., 2010). There was also a research on sedimentation modeling using SWAT for the southwest part of Iran that considered uncertainty analysis (Rostamian *et al*., 2008).

Excessive application of organic and mineral nourishments in severe agricultural regions has resulted in pollution at the western part of Iran. Such pollution caused by nitrate and nitrate leaching had also been investigated using SWAT models to study the non-point pollution capability (Akhavan *et al*., 2010a, b). Understanding the effect of climate change on various components of the water cycle is important due to increasing levels of societal demand. It leads to strategic importance in management of this essential resource. These issues are more pressing in arid to semi-arid regions and have triggered related climate change impact evaluation using SWAT and the Canadian Global Coupled Model (CGCM 3.1) (Abbaspour *et al*., 2010).

Distribution of surface waters for agricultural use is a main problem in arid and semi-arid regions. In Iran where arid and semi-arid climate prevail, 92% of the fresh water is constantly withdrawn for agriculture and farming. Across the globe, 70% of water withdrawal on average is used for irrigation where 18% of it is directed to croplands. The other 30% are for industrial and domestic use (Balon and Dehnad, 2006). Thus, modeling watersheds and performing related analysis is important for such areas where water is a precious resource. Moreover, such modeling can be useful in finding the weaknesses and strengths of SWAT in the outlining of practical sustainable development schemes.

Our study evaluated the Roodan watershed for monthly discharge. This watershed has high intensity of precipitation, but only for a short period of time. Nevertheless, it has considerable volume of surface water for collecting. From an economical point of view, this watershed is important in the south of Iran since this part of Iran produces different agricultural products. In past decades, three grand governmental centers located within the Hormozgan province (Regional Water Joint Stock Company, Agricultural Jihad Organization and Department General of Natural Resources) have done extensive studies in the field of water resources in this watershed (Ab Rah Saz Shargh, 2009). Their results had provided some ideas for this present study. The objectives of this study were:

- To validate the SWAT model in regard with monthly discharge
- To evaluate the simulation of average base flow and average peak flow separately using SWAT

RESEARCH METHODOLOGY

Study area: The study area is located in the southern part of Iran between the Hormozgan and Kerman provinces, which is the Roodan watershed. The area of catchment is 10570 km^2 and lies between northern geographical latitude of 26° and 57 min to 28° and 31 min and the eastern longitude of 56° and 47 min to 57° and 54 min (Fig. 1). For the period of 1978 to 2008, the average annual precipitation was 215 mm. Generally, the climate of Roodan is arid to semi-arid with short and high intensity rainfall. The most important and dominant land use of Roodan watershed are as shrub land (range brush), mix grassland with shrub land and rock. Esteghlal dam is located at the outlet and is important in collecting the surface water for downstream development.

Soil and Water Assessment Tool (SWAT): A number of watershed hydrologic models, namely the Hydrological Simulation Program-Fortran (HSPF) (Johansen *et al*., 1984); Hydrologic Modeling System (HEC-HMS) (USACE-HEC, 2002); Chemical, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980); Erosion-Productivity Impact Calculator (EPIC) (Williams *et al*., 1984); Agricultural Non-Point Source (AGNPS) (Young *et al*., 1989) and Simulator for Water Resources in Rural Basins (SWRRB) (Arnold *et al*., 1990) have been extended for basin assessment. Even though these models are helpful, they have their limitations. For example, some models cannot perform continuous-time simulations without a consistent scale, some are unable to characterize the watershed with enough spatial detail and some cannot provide an optimized number of sub-watersheds (Saleh *et al*., 2000).

SWAT was developed by the U.S. Department of Agriculture (USDA). Compared with other models, SWAT can simulate changes in land management, gives high level of spatial detail, is capable of continuous-time reproduction and can perform efficient computation with limitless number of watershed sections. In SWAT, a watershed is classified into numerous sub-catchments which are then further subdivided into HRUs with homogeneous management, land use and soil uniqueness. The involved hydrological components are precipitation, infiltration, evapotranspiration, canopy storage, surface runoff, lateral flow and return flow. A full description of SWAT model can be found in Neitsch *et al*. (2005a).

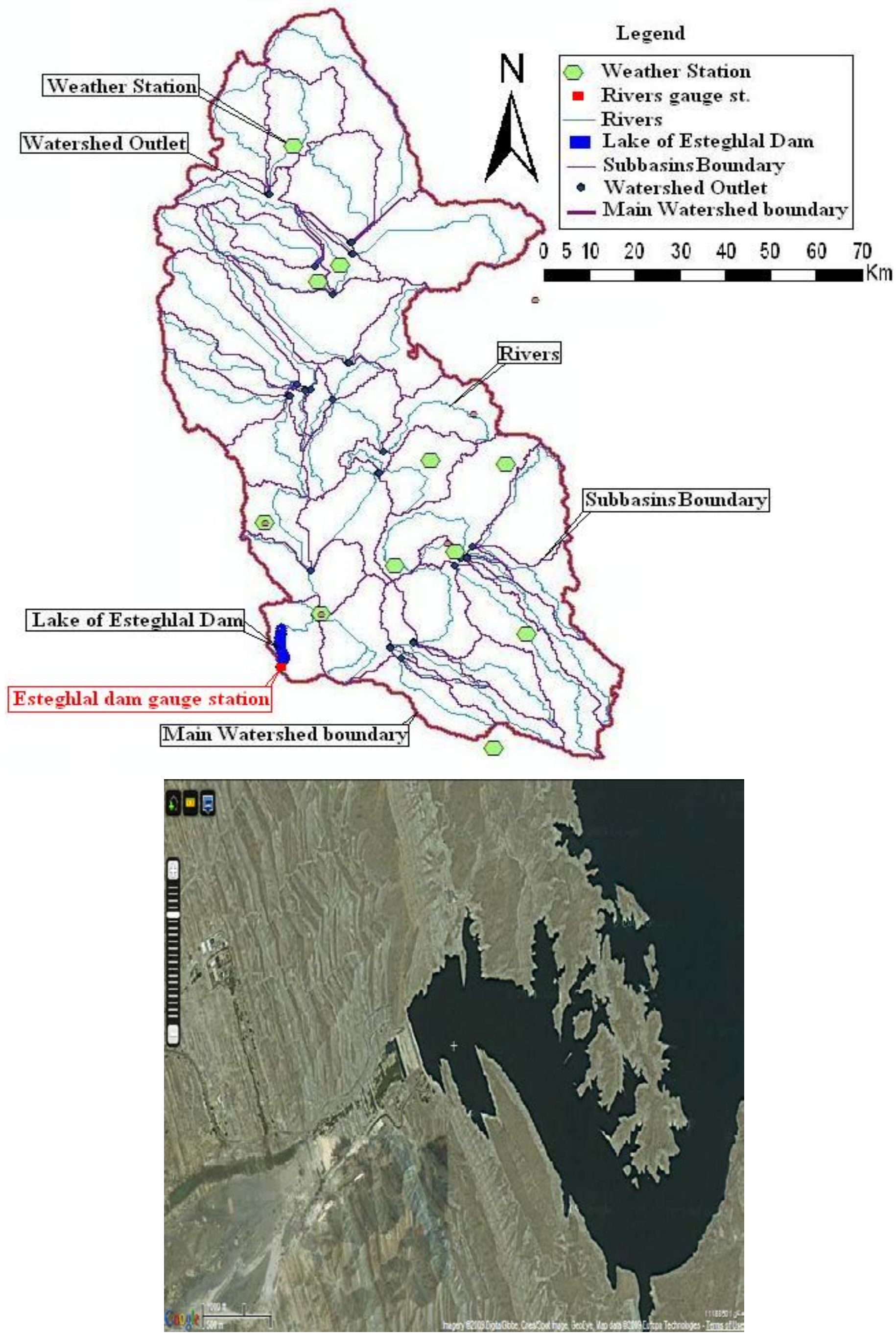

Fig. 1: Roodan watershed in south of iran; satellite image for the reservoir of Esteghalal (Minab) Dam (Ab Rah Saz Shargh, 2009)

SWAT-CUP program: The SWAT-CUP program is a public domain program which is linked to four algorithms to run calibration and validation in SWAT models. These include the Generalized Likelihood Uncertainty Estimation (GLUE) (Beven and Binley, 1992); the Sequential Uncertainty Fitting (SUFI-2) (Abbaspour *et al*., 2007) method; the Parameter Solution (Van Griensven and Meixner, 2006) and the Bayesian inference which is based on the Markov Chain Monte Carlo (MCMC) method. SUFI-2 algorithm, in particular, is suitable for calibration and validation of SWAT model because it represents uncertainties of all sources (e.g., data, model and etc.) (Yang *et al*., 2008). It can perform parameter sensitivity analysis to identify those parameters that contributed the most to the output variance due to input A comprehensive description on the SUFI-2 algorithm can be found in Abbaspour *et al*. (1997).

Evaluation between observed and simulated data was done using the modified coefficient of determination (bR^2), Nash-Sutcliffe (NS) and PBIAS (Krause *et al*., 2005). Equation (1) shows the equation used to determine bR^2:

$$bR^2 = \begin{Bmatrix} |b| \times R^2 \, for b \le 1 \\ |b|^{-1} \times R^2 \, for b > 1 \end{Bmatrix} \tag{1}$$

where,

R^2 = The coefficient of determination between the observed and predicted signals

b = The slope of the regression line

By weighing R^2 under-or over the regression line, predictions are quantified with each other by dynamics. This leads to a more complete reflection of model results. The value of NS is acceptable to be ideally one, but the following equation can be used for hydrological models analysis:

$$NS = \begin{Bmatrix} \dfrac{\sum_i^n (Q_{sim} - Q_{obs})^2}{\sum_i^n (Q_{obs} - Q_{ave})^2} \end{Bmatrix} \tag{2}$$

where,

n : The number data, Q_{sim}

Q_{obs} : The simulated and observed stream flow at time step *i*

Q_{avg} : The average observed stream flow over the simulation period

It has been assessed that if the absolute value of PBIAS ranges from 15 to 25, the SWAT model is rated as 'satisfactory'. From 10 to 15, the model can be rated as 'good' and the model is 'very good' when the value is smaller than 10 (Moriasi *et al*., 2007). PBIAS was estimated as follows:

$$PBIAS = \begin{Bmatrix} \dfrac{\sum_i^n (Q_{obs} - Q_{sim}) \times 100}{\sum_i^n (Q_{obs})} \end{Bmatrix} \tag{3}$$

where, Q_{obs} and Q_{sim} are measured and predicted values at time step *i*. PBIAS is an absolute value measurement of a model's capability to simulate data.

Implementation of SWAT: Generally, required data for the SWAT model development include DEM, land use map, soil map and meteorological data in daily or sub-daily scale (Winchell *et al*., 2010). The metrological data used were temperature, precipitation. In Roodan watershed, the DEM was prepared with a 90 m resolution from 1:25000 topographic maps provided by the Iran topography organization. A mesh size map between 50-90 m resolutions is sufficient for SWAT models (FitzHugh and Mackay, 2000). DEM is based on the delineation of stream river networks and geometry features of basin such as area, slope, slope length and features of channels. It specifies the optimal sub-watershed area to be considered (Arabi *et al*., 2006). FAO soil map was used since it provided information on 5000 soil types and related properties. Then, the land use of Roodan was prepared in accordance to the satellite image of Landsat7 (2002), data extracted from various case studies (2007-2008), available land use map (1:25000) and statistical data from the agriculture organization of Hormozgan, Iran. The available information from satellite image and statistics showed that important land uses did not change more than 2% for the whole observation period. It has been reported that if land use changes is under 5%, then it need not be considered for large scale modeling (Oeurng *et al*., 2011).

Many semi-arid and arid basins have ephemeral channels that take large quantities of stream flow (Ehigiator, 2009). However, SWAT, developed to estimate transmission losses in the absence of observed inflow-outflow data, assumes no lateral inflow or out-of-bank flow contributions to runoff. In contrast, it considers procedure of transmission losses using the method of water balance routing in channels (Neitsch *et al*., 2005a, b).

In the present study, 5% was specified for land-use, soil and slope distribution in HRUs definition stage as this assumption had been reported as appropriate for large basin modeling. The Roodan watershed was divided into 513 HRUs and 45 sub-basins. Finally, the model was set to run for the time period of 1988-2008 with one-year warm-up period.

Sensitivity analysis and calibration scheme: A sensitivity analysis identifies the responses of dissimilar model parameters concerning the simulation of different processes within the model. So, sensitivity analysis is important to optimize the number of parameters for future calibration.

In this study, for finding the sensitive parameters in Roodan watershed, the Latin Hypercub-One-Factor-At-a-Time (LH-OAT) algorithm was applied before calibration. The LH-OAT design is a very useful method for SWAT modeling as it is able to analyze the sensitivity of many parameters. This algorithm is embedded in the SWAT model. The LH-OAT merges the One-factor-At-a-Time (OAT) plan and Latin Hypercube sampling by using the Latin Hypercube example as primary points for an OAT design. The OAT design is an exemplar of the incorporation of a technique that changes a sensitive parameter from local to global sensitivity. The LH-OAT sensitivity analysis method, on the other hand, combines the strength of the

Latin Hypercube sampling with the accuracy of an OAT design. Therefore, the full variety of all parameters can then be modeled by assuring that all outputs can be unambiguously attributed to the appropriate input data.

The present study used 26 hydrological parameters for sensitivity analysis, as suggested in the user's manual of SWAT 2009. In our study, after finding the sensitive parameters on stream flow simulation, we used the SUFI -2 algorithm in SWAT-CUP software to calculate the sensitivity of each parameter prior to the calibration phase. This allowed us to have better judgment on the degree of sensitivity and significance of the parameters. It is a desirable procedure because the analysis is in-depth and thus will help in simulating better models. Then, the calibration periods were defined from 1989 to 2002 and the validation period was from 2003 to 2008.

RESULTS AND DISCUSSION

Assessment of sensitivity analysis: According to the cognition characteristics of case study and sensitivity analysis by SWAT-CUP 2009 tool, 12 parameters were found to be highly sensitive in the Roodan watershed, as presented in Table 1. The results showed that the parameters were primarily those representing channel, runoff, soil processes; these are presented in bold type in Table 1.

Assessment of stream flow: For goodness-of-fit judgment of the model (Table 2), the bR^2 and NS were obtained at 93 and 92%, respectively for calibration. For validation period, bR^2 and NS were found to be 69 and 83%, respectively. The PBIAS for both periods were in permitted range 23% (calibration) and 5% (validation).

The correlations among the average monthly precipitation, observed and simulated monthly discharge were identified over the period of modeling (1989-2008). The results are as shown in Table 3. Generally, the results showed a good fluctuation between simulated and observed average monthly discharge and the correlations were consistent. This consistency proved that SWAT can predict discharge for Roodan watershed. Generally, we found a good simulation for Roodan watershed (a small part in south of Iran).

Table 1: List of sensitive parameters and their ranking for Roodan watershed

Sensitivity rank	Parameter	Description
1	**CH_K2.rte**	Effective hydraulic conductivity of main channel
2	**CN2.mgt_SHRB**	SCS runoff curve number for moisture condition II for shrub land
3	**SOL_AWC.sol**	Available water capacity of the soil layer
4	**CN2.mgt_MIGS**	SCS runoff curve number for moisture condition II for mixing grassland and shrub land
5	**CH_N2.rte**	Manning coefficient for channel
6	ESCO.hru	Soil evaporation compensation factor
7	Surlag.bsn	Surface runoff lag coefficient
8	CANMX.hru	Maximum canopy index
9	RCHRG_DP.gw	Groundwater recharge to deep aquifer
10	GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur
11	SOL_K.sol	Soil conductivity
12	ALPHA_BF.gw	Base flow alpha factor

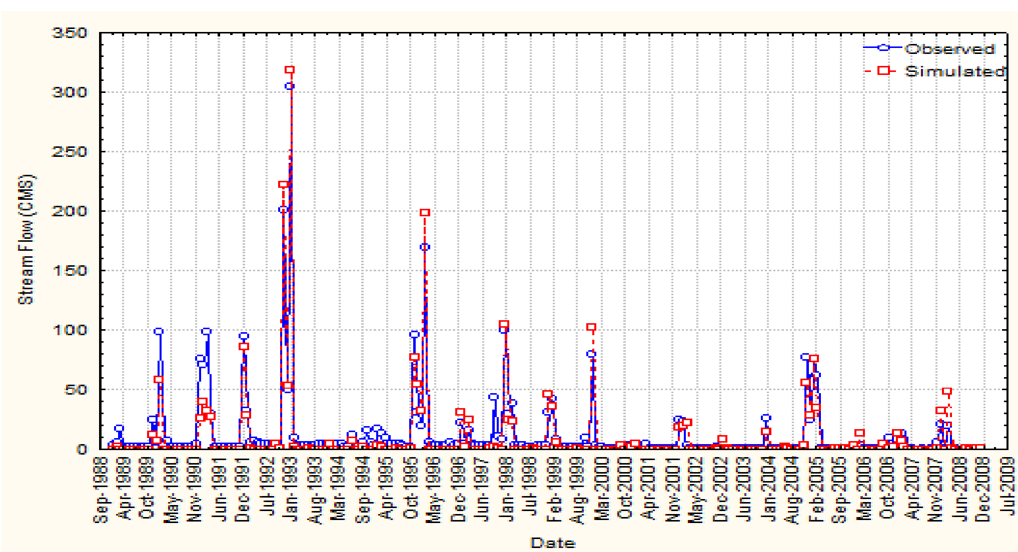

Fig. 2: Monthly observed and simulated stream flow in m^3/s (CMS) of Roodan watershed over modeling period

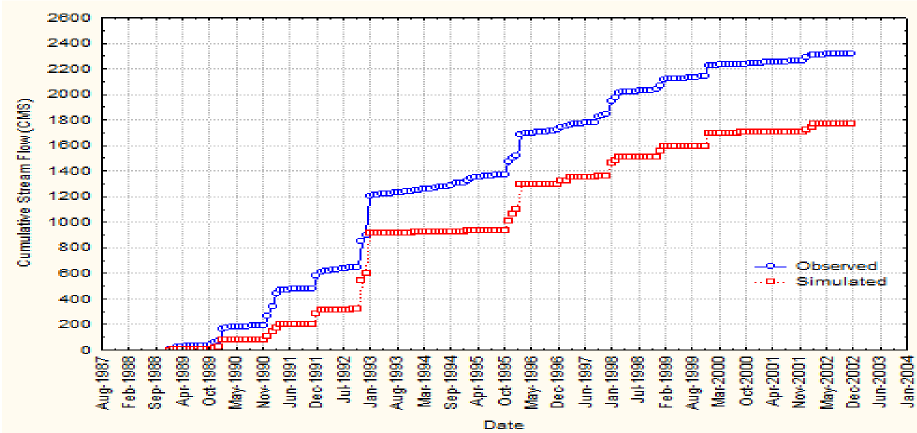

Fig. 3: Cumulative Monthly Stream flow in m^3/s (CMS) over calibration period

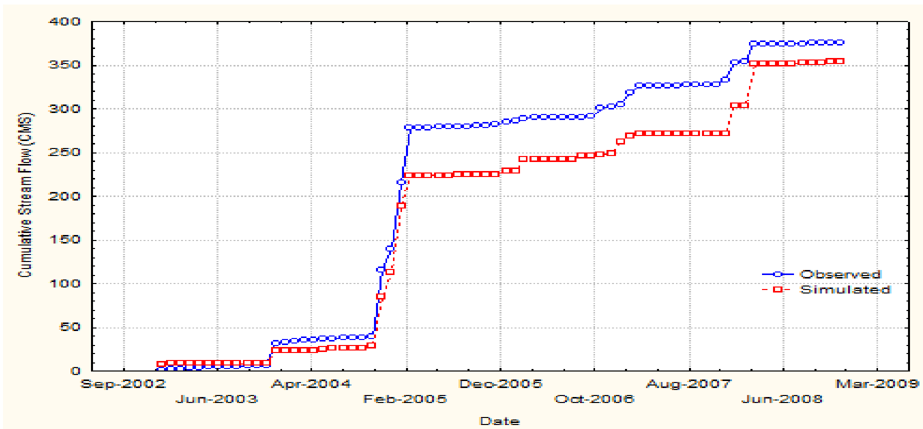

Fig. 4: Cumulative Monthly Stream flow in m^3/s (CMS) over validation period

Table 2: Criteria for examining the accuracy of calibration (1989-2002) and validation (2003-2008) periods for monthly discharge

Index	Calibration	Validation
Nash and Sutcliffe coefficient % (NS)	92	83
Modified coefficient of determination % (bR^2)	93	69
PBIAS (%)	23	5

Table 3: Pair-wise correlation for the stream flow (m^3/s) and precipitation (mm) over modeling period (1989-2008)

	Observed (CMS)	Simulated (CMS)	Precipitation (mm)
Observed (CMS)	1.00		
Simulated (CMS)	0.96	1.00	
Precipitation (mm)	0.89	0.89	1.00

Table 4: Comparison between observed and simulated base flow and peak flow over the entire modeling period (1989-2008)

Type of flow	Mean (m^3/s)	S.D.	Min.-Max. (m^3/s)	Range (m^3/s)
Observed base flow	1.91	2.03	0.03-20	19.07
Simulated base flow	0.65	4.10	0-48	48
Observed peak flow	34.30	51.37	0.20-305	304.80
Simulated peak flow	29.14	54.20	0-318	318

S.D.: Standard deviation; Min.: Minimum; Max.: Maximum

Figure 2 shows a matching fluctuation between the peaks monthly observed and simulated discharge, even though there are some overestimation and underestimation. Figure 3 and 4 illustrate the cumulative monthly discharge analysis for both calibration and validation periods. Both periods showed general underestimation, but the differences in the validation period was smaller than that of calibration period. For calibration, a logical accordance can be seen only in 1989. In addition, for validation period, there was an approximate accordance for observed and simulated data from the year 2003 to 2005.

Assessment of base flow and peak flow: The base and peak flows in this model were reviewed separately, which means that those months with peak flows were alienated from those with only base flows. This resulted in 171 months with base flows and 69 months with peak flows. Generally, most peak flows happened from December to March of the following year.

Table 4 shows that the average simulated base flows over the modeling period was three times lesser than that of observed base flows. The standard

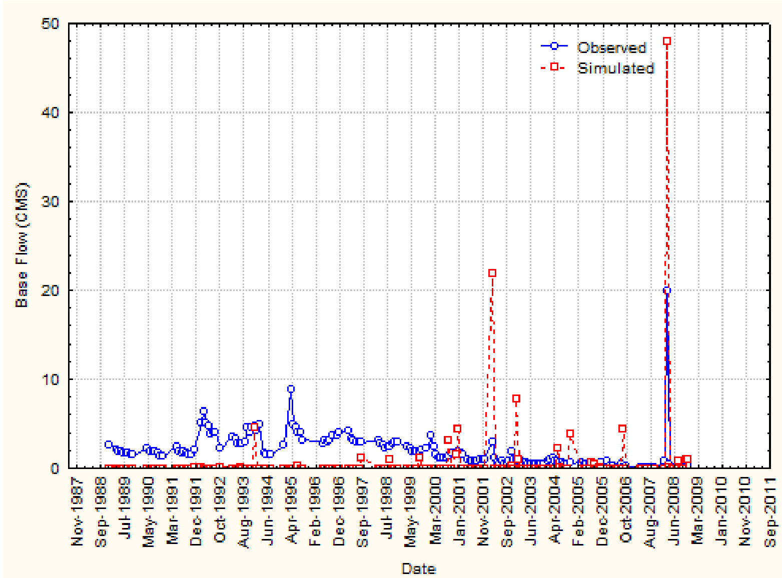

Fig. 5: Observed and simulative base flow over 1989-2008 for Roodan watershed

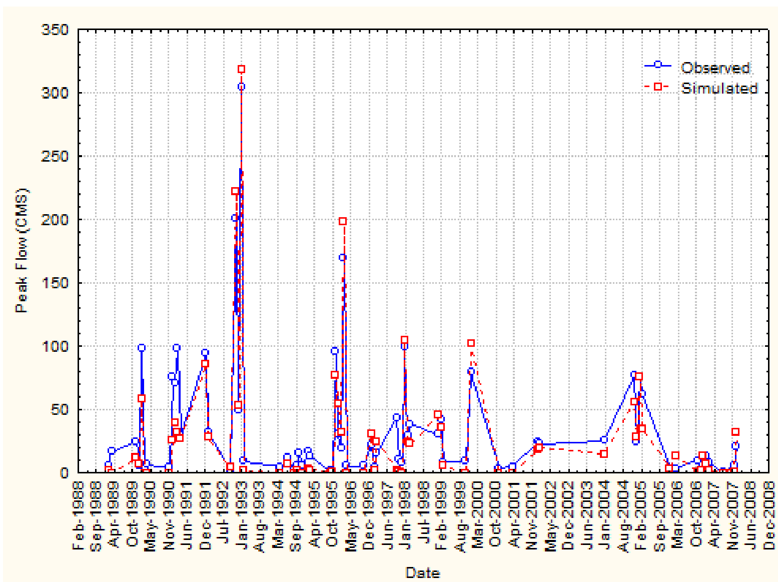

Fig. 6: Observed and simulated peak flow of Roodan watershed over the period of 1989-2008

deviation for simulated base flows was two times more than observed base flows. Moreover, the simulated maximum base flow was 48 m^3/s, but the maximum observed base flow was only 20 m^3/s.

On average, there was not much difference between the simulated and observed peak flows. The standard deviation was approximately the same as well. The simulated maximum peak flow was 318 m^3/s and the maximum observed peak flow was reported at 304.8 m^3/s. Table 4 shows that SWAT performed better in simulation of monthly peak flows.

Figure 5 and 6 depict the average monthly base flow and average monthly peak flow separately. In Fig. 5, the observed base flows decreased when the time increased. This happened due to a decrease in precipitation as a result of global warming and an increase in water usage by the expanding population and industry (Balon and Dehnad, 2006). In contrast, SWAT had simulated a relatively smooth trend for base flows; the base flow simulation from 1989-2000 had been underestimated (Fig. 5). In addition, Fig. 6 shows that the fluctuation for simulated and observed peak flows is approximately the same and logical. Generally, the simulation of peak flows is satisfactory.

Nevertheless, a lack of information regarding the aquifer systems, both deep and shallow, can impact on the base flow modeling. Indeed, temporal varies in the origin and constitution of the, hydrologic, recharged water and human factors may result in periodic varies in groundwater mechanism. These changes can be attributed with nature phenomena or human activities (Karmegam *et al*., 2010). In SWAT model, the return flow to streams is derived from shallow aquifers within the watershed. This means that if there is no sufficient information on the ground water system and lateral flows of a basin, then the SWAT model will be relatively weak.

CONCLUSION

The study used SWAT for simulation of monthly discharge in Roodan watershed located at the southern part of Iran. As a semi-distributed model, SWAT needs lesser data for simulation in contrast to fully distributed models. The sensitivity analysis was performed using the LH-OAT method embedded in the SWAT package. Twelve parameters regarding routing and management files were found to be the most sensitive parameters for calibration. Then, the SWAT-CUP program (SUFI-2 algorithm) was used for calibration and more in-depth sensitivity analysis. To summarize, this study reviewed the average monthly base flow and average monthly peak flow simulation separately. Results showed that the SWAT model underestimated the base flows, but the peak flows had been simulated in a logical fluctuation. The results reveal a hopeful evaluation for practical use of water resources in the Roodan watershed.

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