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Comparison of Single-site and Multi-site Based Calibrations of SWAT in Taleghan Watershed, Iran

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ABSTRACT

Calibration of model is a critical role for hydrologic modeling in a large mountainous watershed. In this study, Soil and Water Assessment Tool (SWAT) was calibrated in single-and multi-site approaches to simulate streamflow. In single-site calibration, a streamflow measurement at outlet of watershed was used for calibration of SWAT. Whereas in multi-site calibration approach, we used streamflow measurements at three stations namly Galinak, Joestan and Dehdar stations. The results showed that the single-site calibration was able to sufficiently simulate the streamflow for Galinak, Joestan and Dehdar stations (Nash-Sutcliffe criteria (NS: 0.66–0.81). The results of multi-site calibration method also showed slight improvement in Galinak, Joestan and Dehdar stations, whereas it was improved in upper stations i.e. Joestan and Dehdar (NS: 0.70–0.82). But, in validation period, there were clearly adventage of results provided using multi-site calibration procedure (NS: 0.78, 0.63 and 0.64 for Galinak, Joestan and Dehdar stations, respectively) compared to single-site calibration method (NS: 0.74, 0.61 and 0.50 for Galinak, Joestan and Dehdar stations, respectively). The results of this study showed that the multi-site calibration method improved calibration of SWAT.

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1. INTRODUCTION

Understanding the hydrologic processes in watershed scale and their prediction are the challenging tasks of hydrologists, as the natural, complex processes in watershed scale are difficult to understand and simulate. Therefore, for the past decade a number of watershed scale hydrologic models have been developed to predict such processes [1-8]. Distributed and semi-distributed hydrologic models have usually a large number of parameters to describe the hydrological process. These models are being increasingly used to solve complex problems in water resource applications including environmental impacts of land-use changes, effects of climate change on water resources, and water planning and management in a catchment [4, 7].

Soil and Water Assessment Tool (SWAT) is a continuous simulation large scale hydrologic model that operates on a daily time step and is designed to predict the impacts of land management on the water yield of large gauge watersheds [9-12]. SWAT provides physically based algorithms as an option to describe many of the important components of the hydrologic cycle. SWAT simulates energy, hydrology, soil temperature, mass transport and land management at subbasin and hydrologic response unit (HRU) level [11].

Hydrologic models, such as SWAT, often contain parameters that cannot be measured directly due to measurement limits and scale issues [13]. These parameters need to be estimated through an inverse method by using calibration so that observed and predicted output values are in agreement.

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A calibration technique should be selected according to the efficiency of the algorithm and the demands of the study [4, 9]. The hydrologic components (such as stream flow) are highly variable, both on a spatial and temporal scale. Therefore, approach of calibrating such models before they can be applied to make watershed decisions is always a challenge [7]. Single gauge calibration has commonly been used for hydrological modeling. This is inevitable in a region where there is only one gauge or small watershed. But, researches express that it is usually required to carry out a careful model calibration in order to obtain an internal consistency of results. This is particularly true for modeling large-scale watersheds that have more diverse hydrological conditions than small watersheds [2, 4, 7, 8, 14, 15]. Also, mountainous watersheds usually exhibit great heterogeneity in geology, topography, soil, vegetation, and climate. Therefore, the use of multi-site observed data to evaluate model performance have been extensively reported [8, 16]. Therefore, the data of only one gauge may not be capable of characterizing the spatial and temporal variability over a large watershed. In this way, researchers have attempted to compare the single and multi-gauges calibration. Previous comparisons between these two calibration methods have been conducted by some researchers [2, 4, 8, 14, 15]. However, this conclusion is a site specific and may not suit the conditions of other areas. Mountainous regions in Iran are important sources of surface water supply and groundwater recharge. Mountains can be the source of a large fraction of annual streamflow in river basins. Therefore, accurate simulation of hydrological processes in mountains at large scales is important for water resource management and for local and regional economics. In this regard, the objective of this study is to investigate whether there are significant differences between multi-gauge and single-gauge calibrations in hydrological modeling for the Taleghan mountainous watershed in Iran.

2. MATHERIAL AND METHODS

2. 1. Study Area The Taleghan watershed, with drainage area of 940.8 km^2, located in the Sefidroud basin, which is an important source of water supply for the Tehran province, Iran, was selected for this study. The elevation of this region is from 1700 to 4370 m above sea level with weighted average of 2,753 m a.s.l.

TABLE 1. Streamflow gauge stations in Taleghan watershed

No	Streamflow gauge name	Area (km^2)	Elevation (m)
1	Galinak	805	1820
2	Joestan	412	1940
3	Dehdar	48	2240

The highest proportion of the study area belongs to the elevation class of 2,500-3,000 m a.s.l. with 35% of the total area, while the lowest proportion belongs to the 4,000-4,500 m a.s.l class with 6% of the area. According to the study of FAUT [17], most of the precipitation in the study area takes place as snow. Because of orographic effects, the average annual precipitation ranges from about 454 mm at the outlet (Galinak station) to more than 814 mm at the upper end of the watershed (Dizan station). The watershed's hydrology is dominated by high volume flows occurring in the spring due to snowmelt, with peak flows also occurring due to spring rainfall events [18].

The daily stream flow data of three hydrological gauges namly Dehdar, Joestan and Galinak stations were collected from Iranian Water Research Institute. Table 1 shows information about selected hydrologic gauging stations in the studied watershed.

The locations of the Taleghan watershed and three streamflow monitoring gauges are shown in Figure 1. Also, data of seven climatological stations located inside the catchment were analyzed. The land use of the studied watershed comprises of 90 percent under poor and good rangelands and 10 percent under orchid agriculture and others land use. The soil textures of the watershed mainly are silt loam and loamy.

2. 2. Input Data Required SWAT model needs a lot of data to be defined for the physical watershed. This would be data about topography (Digital Elevation Model), climate (daily measured and monthly statistical weather data), and both soil and land use (maps and physical parameters) [10, 11]. Data availability as well as quality for a watershed can increase the accuracy of model predication. Daily streamflow, rainfall and temperature data were collected from the Iranian Water Research Institute, Tehran. Table 2 shows positions of meteorological stations in the studied watershed.

A land use map for the year 2008 was derived from image processing using Thematic Mapper (TM) image. For this purpose, point sampling from land use locations in the watershed was carried out using geographic posioning system (GPS). Also, radiometric and geometric corrections have been done, then, supervised method was used for land use classification. A digital elevation model (DEM) was collected from the National Cartographic Centre of Iran (grid: 30 m×30 m); A 1:50000 pedological soil map was available from the Faculty of Agriculture, University of Tehran (1993) as well as some textural soil profiles description for all the major soils. Land use and soil maps used in this study, are shown in Figure 2.

The first process was watershed delineation which splitted the basin into 37 subbasins (Figure 1) according to the terrain and river channels. Further division into multiple hydrological response units (HRUs) comprising of unique land use, soil, and land use management was based on user-defined threshold percentages [10]. The next step was upload of the rainfall and weather data files. The final stage was writing input files with required input data for the project.

2. 3. Model Calibration Hydrologic models such as SWAT, often contain parameters that cannot be measured directly due to measurement limits and scale issues [13, 15]. Inverse modeling (IM) has in recent years become a very popular method for calibration [9, 19]. IM is concerned with the problem of making inferences about physical systems from measured output variables of the model (e.g., river discharge, sediment concentration). This is attractive because direct measurement of parameters describing the physical system is time consuming, costly, tedious, and often has limited applicability.

The Sequential Uncertainty Fitting version-2 (SUFI-2) procedure was used to calibrate the SWAT model in this study. It is an inverse optimization approach that uses the Latin hypercube sampling (LHS) procedure along with a global search algorithm to examine the behavior of objective functions. The LHS method is a stratified sampling technique where the random variable distributions are divided into equal probability intervals.

Firstly, parameters are divided into the indicated number of simulations. Secondly, parameter segments are randomized. Finally, a random sample is taken in every segment and the combination forms a parameter set. The initial parameter ranges can be updated for every iteration, and the recommended new parameter ranges are always centered on the current best estimate. This program is currently linked to SWAT in the calibration package SWAT-CUP (SWAT Calibration Uncertainty Procedures) [4, 20].

Figure1. Taleghan SWAT watershed delineation with 31 sub-watershed, gauging station, stream networks and the digital elevation model

TABLE 2. List of selected rainfall and temperature stations in this study

Station name	X (UTM)	Y (UTM)	Elevation (m)
Dehdar	506043	4006472	2800
Garab	506245	4002652	2600
Joestan	490234	4004812	1990
Dizan	484904	4013508	1950
Sekranchal	475977	4015500	2200
Geliroud	491252	3999080	2150
Zidasht	471670	4002880	1750

Two parameterization schemes were conducted for daily stream flow simulations. One was the multi-gauge calibration, and the chosen parameters were calibrated simultaneously by using all the hydrological data of the Dehdar, Joestan and Galinak gauges. The other was single-gauge calibration at Galinak for whole watershed.

2. 4. Model Performance Evaluation Performance was evaluated through visual interpretation of the simulated hydrographs, and commonly statistical measures of agreement between measured and simulated stream flow was used. Several statistical criteria were used to check the model performance, viz. coefficient of determination (R^2) and Nash-Suttcliffe efficiency (NS) [21, 22]. The R^2 value is an indicator of relationship strength between the observed and simulated values. Values of the NS coefficient can range from negative infinity to 1. NS coefficients greater than 0.75 are considered ''good,'' whereas values between 0.75 and 0.5 are considered as ''satisfactory'' [22].

3. RESULTS AND DISCUSSIONS

Initial model simulations were conducted using default values for the most model parameters. Potential evapotranspiration (PET) was modeled with the Hargreaves algorithm. Surface runoff was modeled with the Curve Number. This simulation passed through three consecutive separate periods. These, as well as their durations, were: (i) the setup (also known as warm-up) period (1 year); (ii) the calibration period (3 years), and (iii) the validation period (2 year). After providing required input data, SWAT was run for daily streamflow in Taleghan river. Comparison of the estimated and observed values showed that the SWAT significantly overestimated in rainfall and snowmelt events but, generally underestimated the streamflow in the studied watershed.

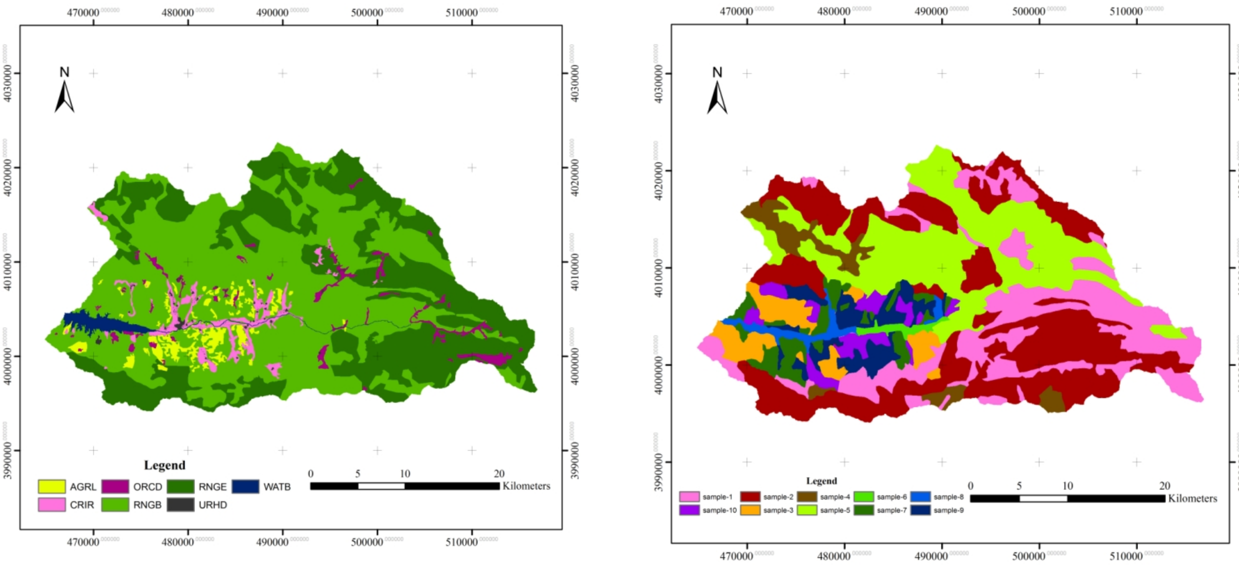

Figure 2. SWAT land use (A) and soil type (B) classification of the Taleghan watershed

TABLE 3. SWAT model parameters and calibrated value in multi-site calibration method

Parameter	Calibrated value
r__CN2.mgt	0.05
v__ALPHA_BF.gw	0.056
v__GW_DELAY.gw	7.5
v__CH_N2.rte	0.11
v__CH_K2.rte	51
r__SOL_AWC(1).sol	-0.08
r__SOL_K(1).sol	-0.12
v__SNOCOVMX.bsn	288
v__SNO50COV.bsn	0.50
v__SURLAG.bsn	7.70
v__SMFMX.bsn	4.9
v__SMFMN.bsn	4.11

v__ parameter name means the existing parameter value is to be replaced by the given value and r__ parameter name means the existing parameter value is multiplied by (1+ a given value)

TABLE 4. Statistical evaluation of different calibration methods in this study

Site name	Multi-site calibration		Single-site calibration	
	R^2	NS	R^2	NS
Dehdar	0.75	0.70 (0.63)	0.71	0.66 (0.50)
Joestan	0.84	0.72 (0.64)	0.80	0.70 (0.61)
Galinak	0.82	0.80 (0.78)	0.80	0.78 (0.74)

Numbers in parentheses are validation result.

The determination coefficients were 0.09, 0.14 and 0.17 in Dehdar, Joestan and Galinak stations, respectively. Figure 3 shows simulated and observed time series of runoff in three streamflow gauge stations. In calibration processes, over-parameterization is a well-known and often described problem with hydrological models [23], especially for semi-distributed models such as SWAT [23, 24]. In this study, 12 parameters of the SWAT (listed in Table 3) affecting the streamflow were identified through a detailed literature review especially in mountainous region with dominant snow regime [9, 21, 25, 26]. The initial range of each parameter was determined according to the recommendations from Neitsch et al. [11] and Abbaspour [9]. During the calibrating process, SWAT-CUP changed the parameters based on their existing values. After selecting appropriate parameters, SWAT was calibrated using two methods: 1) calibration made only in Galinak station (outlet) but examined in three stations (Galinak, Joestan and Dehdar) and 2) calibration and performance efficiency simultaneously made in three stations.

Statistical results of single-site and multi-site calibration of SWAT in Taleghan watershed are showen in Table 4.

3. 1. SWAT Performance The results showed in two calibration strategies, measured and simulated daily streamflows have a good match with slightly under-predicted in some days. The results were higher than the recommended minimum values in the literature (R^2>0.6 and NS>0.5), which illustrates that SWAT has represented the whole process that occurred in the watershed with sufficiently close output compared to the observed output [22]. The results showed, SWAT consistently underestimated daily streamflow. The same results were reported in regions dominated snow where snow plays a key role in streamflow generation[26, 27]. These trends may be explained in terms of simple temperature-index method in snowpack and snowmelt modeling used in SWAT. Topographic effects, aspects, slope, different land uses, and land cover have an effect on snow development and melt processes. Such processes are, however, not well represented in the simple temperature-index method [26, 27]. Also, SCS method cannot simulate runoff from melting snow and on frozen ground. The model also routed water out of the ground-water reservoir faster than under field conditions [21].

3. 2. Single-site vs. Multi-site Calibration The overall results indicated that two schemes, with slight difference, yielded acceptable simulation results. This result is consistent with Cao et al. [2]. Zhang et al. [15] and Gong et al. [4] results that reported acceptable results for both single and multi-calibration.

In calibration period, the results clearly indicate that two calibration approaches have similar R^2 and NS in outlet station. But, while using multi-site calibration, the R^2 and NS values were higher in the internal stations (Joestan and Dehdar) than single-site calibration.

In validation period, the results clearly indicate that the multi-site calibration has persistence modeling in Taleghan watershed, because it has better hydrologic simulation in validation period. Therefore, multi-site calibration could reduce uncertainties from equifinality problems during parameterization of SWAT using inverse modeling.

Watershed modeling using SWAT could be explained by these results. In SWAT the hydrological simulation is conducted on the HRU basis; therefore many important parameters are determined on the basis of combinations of land use, topography and soil [4]. In the Taleghan watershed land uses, soil type and slope variations were non uniform across the watershed. Therefore these parameters had impact in this study.

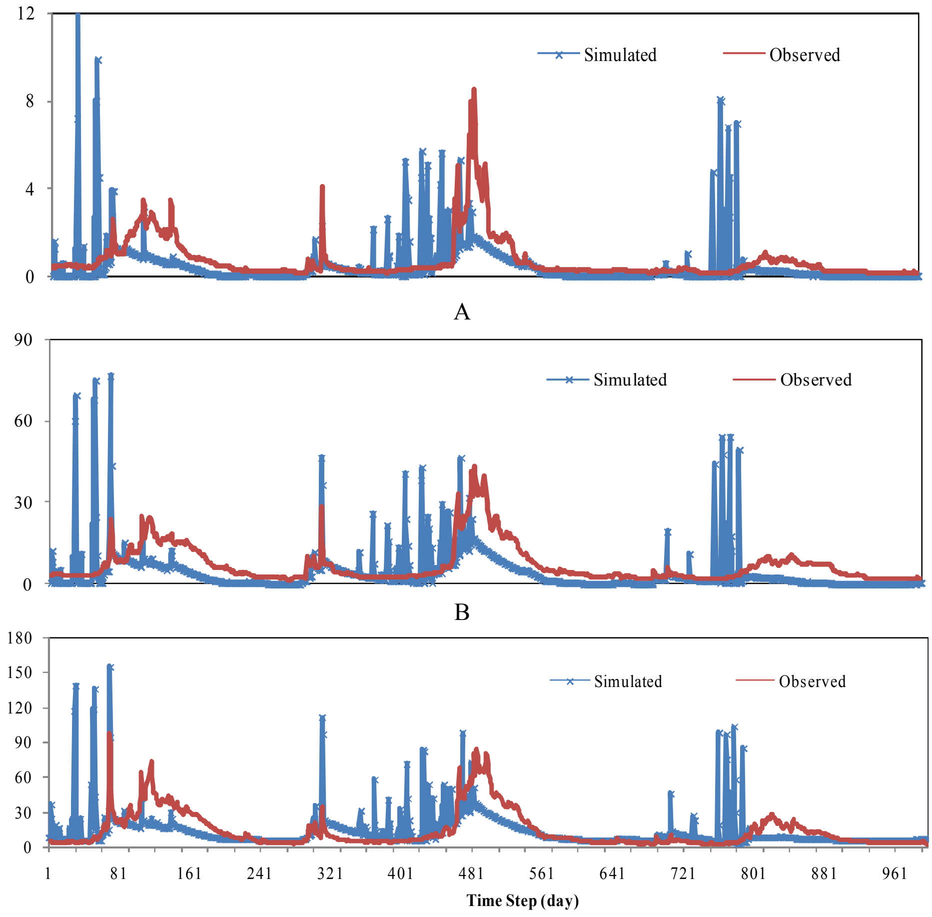

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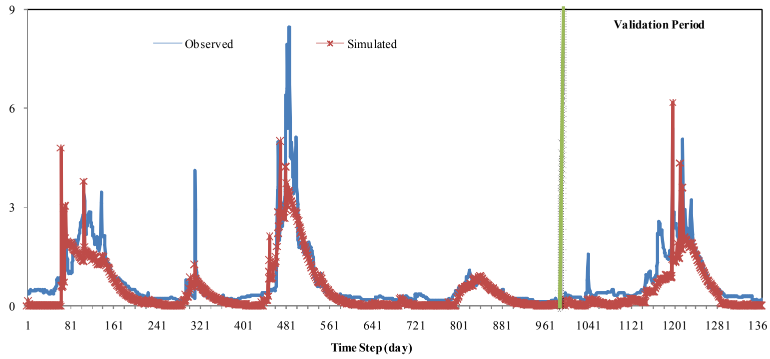
Figure 3. Graphical presentation of observed and not calibrated SWAT simulated in Dehdar (A), Joestan (B) and Galinak (C)

In overall view, the multi-site calibration could obtain better model performances than single-gauge scheme especially at inside gauge. This finding differs from Gong et al. [4] that reported no differences between the simulation results obtained by the multi- and single-site calibration schemes. It is possible to achieve good modeling performances for single-site calibration because the land uses and soil types are uniformly distributed across the watershed and the topography variations are similar for different subwatersheds of the studied watershed. But, in Taleghan watershed because of mountain condition, soil type, land use and topography in upstream which was different from downstream, multi-site approach was better than single-site strategy. It agrees with findings of Cao et al. [2] in mountainous catchment with high spatial variability and results of Niraula et al. [14] in semi arid watershed.

Figure 4 shows predicted daily streamflow against the measured at Galinak, Joestan and Dehdar obtained from multi-site calibration.



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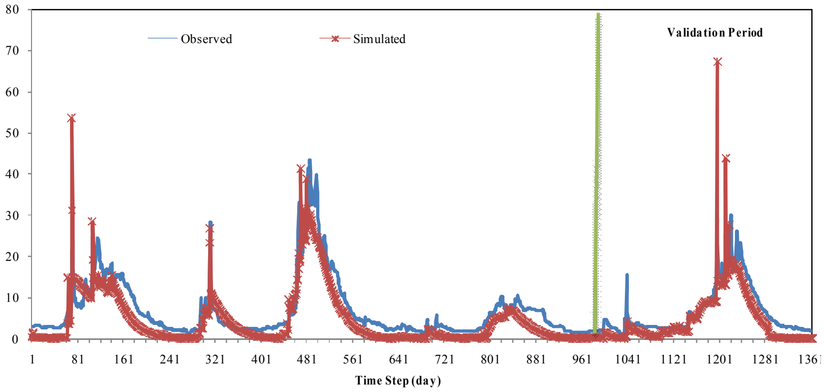

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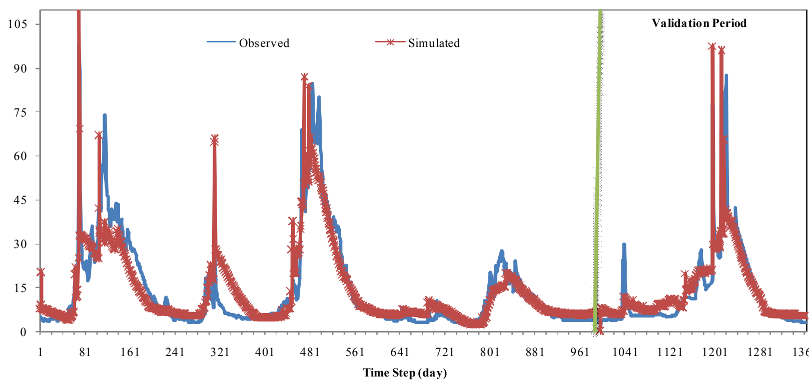

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Figure 4. Observation and simulation streamflow time series in Dehdar (a), Joestan (b) and Galinak (c) in calibration and validation period

Finally, Migliaccio and Chaubey [28] stated that although nested data sites may be commonly found due to monitoring strategies, non nested or mutually independent sites provide a better format for multi-site calibration, since each site contributes to a larger area but there are no catchment area overlaps. But, there are a limited number of hydrological gauges within the Taleghan watershed that is not mutually independent site.

4.CONCLUSIONS

The objective of this study was to best simulate surface water flow in Taleghan watershed and evaluate the effect of single and multi-site calibration on flow predictions. The results indicated that single streamflow and multi-site calibration, yielded acceptable simulation results. In comparison, when the model was established with a multi-site calibration at the watershed, streamflow predictions were improved especially in inside gauge and validation period. This study indicates efficiency of multi-site calibration in streamflow simulation. But, in this study some parameters during the calibration, can only have single values across the whole watershed, if these parameters could be assigned by different values for different sub-watersheds, there might be better simulation results for the multi-gauge calibration. In general view, this study suggests that hydrologic model calibration at the watershed level can improve performance for the internal station simulation.

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چکیده

واسنجی یک مدل هیدرولوژیک در حوزه های آبخیز بزرگ کوهستانی یک مسئله پیچیده می باشد. در این تحقیق مدل SWAT به منظور شبیه سازی جریان حوزه آبخیز طالقان در یک و چند ایستگاه مورد واسنجی قرار گرفت. در این راستا مدل در یک رویکرد تنها در خروجی آبخیز (ایستگاه گلینک) و در رویکرد دیگر در سه ایستگاه هیدرومتری موجود در آبخیز (دهدر، جوستان و گلینک) مورد واسنجی قرار گرفت. نتایج واسنجی مدل در یک ایستگاه نشان دهنده شبیه سازی رضایت بخش دبی در خروجی و ایستگاههای درونی حوزه آبخیز طالقان داشت. همچنین واسنجی همزمان مدل در چند ایستگاه دلالت بر بهبود اندک نتایج شبیه سازی مدل در مقایسه با رویکرد اول داشته است. با این حال در دوره اعتبار سنجی، نتایج واسنجی در چند ایستگاه دارای دقت بالاتری نسبت به رویکرد اول بود. نتایج تحقیق حاضر دلالت بر مزیت نسبی واسنجی مدل SWAT در چند ایستگاه داشته است.

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