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Hydrological Simulation of Bakhtegan Basin in Iran Using the SWAT Model

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Abstract

Continuous-time, distributed parameter hydrologic models like SWAT have opened several opportunities to boost watershed modeling accuracy. This study has described the essential parameterization issues involved when predicting watershed stream runoff using SWAT. Understanding these issues is expected to guide to improved SWAT runoff prediction performance. This research describes the important parameterization issues involved when modeling watershed hydrology for runoff prediction using SWAT, emphasizing the thanks to improving model performance without resorting to the tedious and arbitrary parameter by parameter calibration. The Bakhtegan watershed was used to illustrate runoff prediction's sensitivity to spatial variability, watershed decomposition, and spatial and temporal adjustment of curve numbers and return flow contribution. The SWAT model finishes hydrological simulation with good performance calibration (2006 to 2012) and validation (2013) periods. SWAT was also conversant in predict runoff from Bakhtegan that has extensive subsurface drainage. If properly validated, the study showed that the SWAT model would be used effectively in testing management scenarios within the Bakhtegan watershed. The result showed that the Nash–Sutcliffe of calibration and the validation between simulated and observed are 0.71 and 0.74, respectively. The SWAT model application, supported by GIS technology, proved to be a flexible and reliable water decision-making tool.

Introduction

Accurate hydrological simulation of a basin needs developing a model considering a good range of detailed information, including the list of cultivated crops and orchards, irrigation schedules, fertilization, and harvesting operations, and then on (Eini, 2019). This detailed information, which constitutes distributed simulation models like Soil and Water Assessment Tools (SWAT), significantly affects percolation and evapotranspiration. Crop yield is of significant concern on a worldwide scale. In line with the Food and Agriculture Organization of the world organization (FAO), from 2013 to 2015, an additional billion of plenty of grain will still be needed every year. In this regard, estimating crop yields' variability under temperature change situations and other hydrological components could also help water decision-

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makers. A common belief is that without an accurate and complete calibration and validation of a model for local conditions of the system, no additional functional analyses in respect of the model estimates are reliable (Smarzyńska & Miatkowski, 2016). Researches have shown that the results of global climate change on various agricultural products won't have a predictable trend because of the sort of product, conditions of the case study, and climate scenarios (Shahvari et al., 2019). In some studies, increased crop yields are reported, and in others, the call-in crop yields have been reported (Boonwichai et al., 2019; Kolberg et al., 2019). The results of a study in the 10 largest producing countries showed that compared to present conditions, a bunch of 11 crop models found an increase in yield loss risk by 12%, 6.3%, 19.4%, and 16.1% for wheat, corn, rice, and soybeans by 2100, respectively (Leng & Hall, 2019). Earlier studies have assessed the potential impact of water shortages under different climate situations on crop production within the US, China, Australia, African country, and on a world scale (Araújo et al., 2016; Madadgar et al., 2017; Matiu et al., 2017). On the opposite hand, the impacts of temperature change on crop yield within the Mideast with numerous arid and semi-arid basins are unknown. This objective is fulfilled by employing semi and fully distributed. During this regard, the SWAT has been widely accustomed to investigate agricultural practices, crop yields, and land management impacts on water quantity and quality considering global climate change scenarios (Arnold & Fohrer, 2005). SWAT could be a semi-distributed process-based continuous continuance geographic region model (Arnold et al., 2011).

Considering the SWAT model's capabilities, different aspects of LULC alteration and temperature change on sedimentation, eating away, and runoff magnitude are investigated. Shrestha et al. (2015) evaluated runoff and sediment within the Northwest of Vietnam using SWAT. The results showed that the LULC status contains a significant influence on runoff and sediment yield. Land-use conversion by extension of forested area and employment of soil protection practices during five years (2005 to 2010), leaded to a decrease in both runoff (from 342.7 to 167.6 mm) and sediment yield (from 148.1 to 74.0 ton/ha).

Today, the SWAT model is used worldwide to evaluate climate parameters on the hydrology of the basin. Ghodosi et al. (2013) used the SWAT model to investigate the effect of land-use change on the entrance of the Aji Chai River to Lake Urmia. Using Landsat images from 1976, 1989, 2002, and 2008 as input to the SWAT model and the model for the years 1976 to 2008 were implemented monthly. The results showed that the volume of water leaving the basin decreased by 51%, and actual evapotranspiration increased by 13%, during which land-use changes have played an essential role in reducing the water area of Lake Urmia. Kundu et al. (2017) investigated the effect of land-use change on water balance in a part of the Narmada River Basin in India using the SWAT model. Land-use changes in 1990, 2000, and 2011 were analyzed, and the Markov chain model was used to predict future land-use changes (2020, 2030, 2040, and 2050). The results showed that during the period 1990 to 2050, the value of the CN increased due to the decrease in vegetation and the increase of agricultural lands and residential areas, which increased runoff and decreased actual evapotranspiration, as well as reduced groundwater areas.

In this study, the basin hydrology processes were simulated to investigate these parameters' effects on the hydrological components of the Bakhtegan watershed by using the semi-distributed SWAT model. Simulation results were calibrated in SWAT CUP software.

In the present research, to predict runoff and investigate the trend of surface, subsurface, and underground flow changes in the Bakhtegan watershed, the soil and water assessment model (SWAT) is used. Utilizing soil, vegetation, and DEM maps and combining them with hydro-climatological information in the GIS environment is considered one of the models features in runoff estimation compared to other models. These parameters obtained from the model's calibration are evaluated by using it in the validation period.

This paper looks at the results on watershed runoff prediction of a number of the more fundamental parameterization approaches that a user can adopt when using SWAT. An overall understanding of what methods are available in SWAT and how significantly such policies affect the model prediction is significant in improving model performance because of the modeling process's efficiency. It should be noted that the approaches considered during this study are straightforward and do not require rigorous or arbitrary parameter-by-parameter calibration on the part of the users. Illustrative simulation runs are presented using actual watersheds in Bakhtegan. The main reason for modeling in this area is the simulated swat of Bakhtegan Using the SWAT Model.

Materials and Methods

The Study Area and Statistical Information

The study region has vicinity of about 3227.3 km^2 and is found at the longitude of N 30°14' to 30°59' and latitude of E 51°42' to 52°54' (Fig. 1&2). The altitude of the study area ranges from 694 to 1768 m. The Bakhtegan watershed is drained mainly by the Kor River, with the most part located between Doroudzan dam and Bakhtegan Lake. The overall amount of surface and groundwater flowing into the catchment is about 3521.4 million m3. Groundwater resources supply 79% of the full water needs within the catchment (RASI NEZAMI et al. 2013).

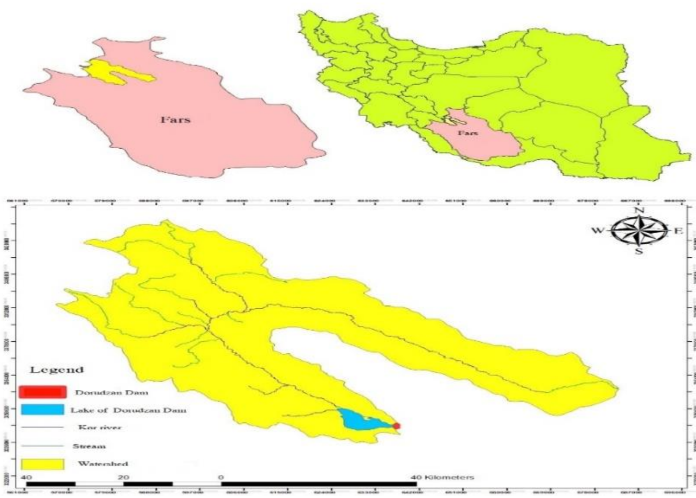

Fig.1- case study of Bakhtegan watershed

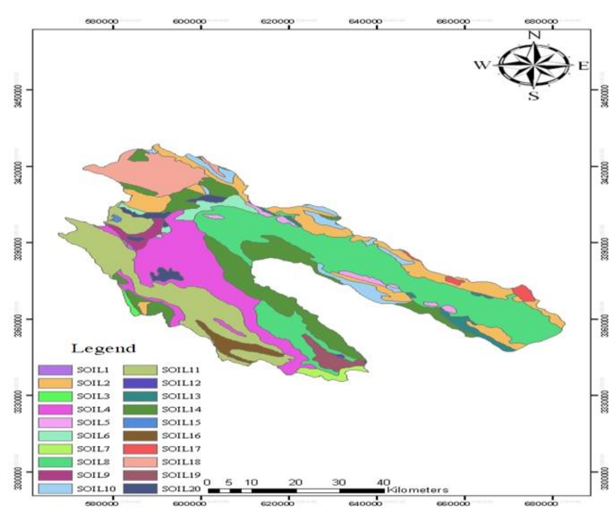

Fig. 2- Map of soil used in modeling

Data Pre-Processing for SWAT

Input for SWAT is defined at one amongst several different levels of detail: watershed, subbasin, or HRU, Unique features like reservoirs or point sources must have an input file provided for every individual part included within the watershed simulation.

Watershed level inputs are accustomed to model processes throughout the watershed. For example, the tactic selected to model potential evapotranspiration is utilized in all HRUs within the watershed. Subbasin level input is inputs set at the identical value for all HRUs within the subbasin if the information pertains to the method modeled within the HRU. Because there's one reach per subbasin, the input file for main channels is also defined at the subbasin level. An example of subbasin level data is rainfall and temperature information. The identical rainfall and maximum and minimum temperature are used for all HRUs, the most channel, and any ponds or wetlands located within the subbasin. HRU level inputs are inputs that will be set to unique values for every HRU within the watershed. An example of an HRU input is that the management scenario simulated in an HRU.

An attempt has been made to arrange input information consistent with the sort of input. However, some files have had to function as "catch-alls." These files contain input files for various processes modeled within the watershed that don't fit into any specialized files.

Modeling of Hydrological Conditions Using SWAT Model

Since this study aims to investigate the hydrological impact of Bakhtegan Watershed, images of TM and ETM + Landsat satellite were used to prepare the required land use maps in 2006. From atmospheric corrections to satellite images in ENVI software, image classification using maximum probability algorithm with acceptable accuracy in seven user classes including barren lands, agricultural lands, gardens, rangelands, residential areas, forest lands, and lakes were surveyed. In the first stage, with the introduction of the Dem map with an accuracy of 30 meters and the production of the flow network by the model itself, based on the threshold of 14,000 hectares as the minimum drainage area and the introduction of Chamriz hydrometric station as basin output, the dam was divided into 11 sub-basins. After drawing the basin's boundary, sub-basin, and flow network, the basin's physical parameters and sub-basin, including area, length of the main waterway, slope, elevation characteristics, etc., are calculated. In the next step, soil and land use maps were entered into the models, and slope classes were defined and combined; hydrological response units (HRU) were generated in each sub-basin. This study introduced three slope classes (0-9.5, 9.5-24, 24<%) to the model. The next step is to introduce climatic data to the model. Daily precipitation and temperature data were entered into the models according to Table (1), and the Hargreaves-Samani method was used to calculate the potential evapotranspiration. The variable storage coefficient method was used for flow routing. In the final step, the model was implemented to simulate the monthly runoff with three years of training for all three models. Also, Chamriz station monthly flow statistics model was used to calibrate and validate. Table (1) presents the specifications of meteorological stations used in the SWAT model.

Table 1- The character of meteorological stations in the Bakhtegan Watershed

Row	Station Name	Station Type	Latitude	Longitude	Elevation(m)
1	Ahmad Abad Chahardangeh	Rain Gauge	30°23´21	52°41´26	2233
2	Jamalbeyg Shirin	Rain Gauge	30°36´30	51°57´21	2010
3	Chamriz	Evaporation Gauge	30°27´57	52°05´40	1789
4	Choobkholeh	Rain Gauge	30°32´51	51°53´58	2056
5	Khosroshirin	Rain Gauge	30°54´5	52°00´39	2340
6	Dehkadeh Sefid	Rain Gauge	30°42´55	52°04´59	2181
7	Sedeh	Evaporation Gauge	30°43´10	52°09´48	2192
8	Ghatar Aghaj	Rain Gauge	31°43´12	51°53´24	2306
9	doroudzan dam	Synoptic	30°10´25	52°27´46	1650
10	Chamriz	Hydrometry	30°27´	52°08´	1840

Developing the SWAT Model

SWAT could be a nonstop time demonstrate that works on a simple time step at bowl scale. Such a demonstration aims to anticipate the long-term impacts in vast bowls of administration and the timing of rural hones inside a year (i.e., edit revolutions, planting and collect dates, water system, fertilizer, and pesticide application rates and timing). It can mimic the bowl scale water and supplements cycle in scenes whose prevailing arrival use is agribusiness. It can moreover offer assistance in evaluating the biological productivity of best administration hones and elective administration approaches. SWAT employments a two-level disaggregation conspire; a preparatory subbasin distinguishing proof is carried out based on topographic criteria, taken after by assist discretization utilizing arrive utilize and soil sort contemplations. Ranges with the same soil sort and arrive utilize frame a Hydrologic Reaction Unit (HRU), a fundamental computational unit accepted to be homogeneous in hydrologic reaction to coming cover alter.

The SWAT may be a long-term, continuous, physically distributed model developed for predicting the effect of land management practices on the hydrology, sediment yield, and water quality in agricultural watersheds (Arnold et al., 2011). The SWAT model is considered a hydrological transport model at the catchment scale and can handle weather, hydrology, erosion/sedimentation, nutrients, channel routing, plant growth, and agricultural management components hydrological simulation. The model is often operated in various time scales from a sub-daily time step to a monthly/yearly duration (Eini et al., 2019). In step with Neitsch et al. (2011), computational simulation costs are minimized within the Hydrologic Respond Unit (HRU) delineating process by lumping similar soil and land-use areas into one unit. The basic structure of the working order of the program is:

1. Initially calculating fluxes separately for each HRU.
2. Aggregating the obtained changes to sub-basin outputs looking at a fraction of the HRUs.
3. Finally, routing outputs of sub-basin through a river reach within the channel network.

A watershed is often modeled by SWAT using three schemes of decomposition. It is subdivided into its natural watersheds to preserve the natural flow paths, boundaries, and channels for realistically routing water, sediment, and chemicals (Fig. 3). It will be subdivided into smaller, relatively homogenous areas, as an example, by superimposing a grid. Routing between the grid elements is simulated. Alternatively, the

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watershed is often represented by using the concept of a Hydrologic Response Unit (HRU), which involves the aggregation of areas related to a novel combination of soil and land use no matter their spatial position within the watershed (i.e., noted as virtual subbasins in SWAT). Since an HRU doesn't correspond to a physical location within the watershed, routing between these units cannot be simulated. The estimated runoff from each HRU is added to get the estimated flow at the watershed outlet. It should be noted that several schemes of decomposition could coincide when modeling one watershed. for instance, a watershed will be subdivided into sub-watersheds that may each be further decomposed using different techniques of decomposition. Presently, there are not any standard procedures for deciding what decomposition scheme to adopt. The more popular choice is to contemplate the full spatial detail because of the time, the model, and the computing resources.

The Dorodzan dam basin, as a part of the Bakhtegan watershed, is employed as an example of the effect of the chosen decomposition scheme. Fig (3) shows the eleven different decomposition schemes that were adopted for the Bakhtegan watershed. The primary technique used the concept of the HRU (a soil and land use threshold were accustomed to identify HRUs) to represent the whole watershed. The second scheme subdivided the watershed into eleven subbasins, each further subdivided into HRUs supported soil and land use thresholds. The last method subdivided the whole watershed into grid elements, with each piece represented the dominant soil and land use. Each decomposition scheme corresponds to a remarkable spatial detail, increasing from the primary to the third scheme.

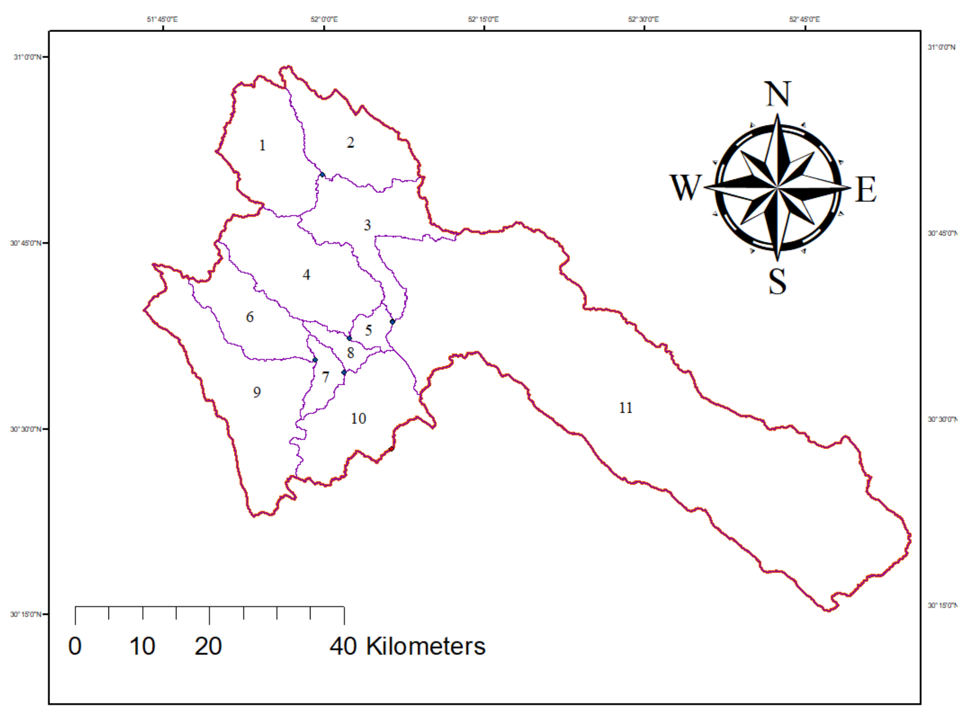

Fig 3- Subbasins of Dorodzan Dam basin

The SWAT model may be utilized for sediment yield predictions to design and manage water resources and reservoir sediment controls at the catchment scale. Sediment yield is the sum of the sediments produced by overland flow, gully, and stream channel erosion in a very catchment. SWAT can even be a possible tool in estimating sediment yield, especially at the catchment scale since the SWAT model's temporal and spatial variation captivated with various potential physical variables is taken into considerations. The model can also provide a superior understanding of overland flow sediment transport and deposition processes and permit sensible prediction and forecasting. The primary factor controlling sediment yield, in general, is that the transport capacity of runoff. Sediment transport within the channel network may be a function of degradation and aggradation (Neitsch et al., 2011). The version of the SWAT model gets employed here, routes the utmost sediment amount in a very reach as a function of the height channel velocity, and calculates sediment yield for every HRU utilizing Modified Universal Soil Loss Equation. The sediment yield transported to the surface runoff was computed using the Modified Universal Soil Loss Equation (Bonumá et al., 2014). For individual HRU, the Modified Universal Soil Loss Equation of sediment yield SEDj,k (t/ha/year) is provided by Eq. (1).

$$SEDj, k = 11.8\ (Qj, kqj, kAj, k)\ 0.56\ Kj, kCj, kPj, kLSj, kCFRGj, k \tag{1}$$

Within the Eq. (1), Qj, k signifies the volume of surface runoff related with the HRU, qj,k is the crest runoff rate, Kj,k is the soil calculate, Cj,k is the trim administration estimates, $Pj,k$is the preservation hone figure, LSj,k is the topographic figure, and $CFRGj,k$ is the coarse part figure. The Modified Universal Soil Loss Equation's real portrayal is well recognized and utilized worldwide to examine water disintegration.

Rural items are calibrated based on the usual bowl waste information counting actual evapotranspiration and a regular surrender of agricultural commodities. One of the main critical parameters within the calibration of agricultural yield is the sum and fertilizer utilized for plants. Moreover, the soil parameters such as profundity of root advancement (RDMX) and soil profundity (SOL_Z) are essential parameters that ought to be explored first and simultaneously with runoff recreation. Sol_BD and Sol_AWC parameters are separately related to soil porosity and water holding capacity of the soil, not as they were essential in runoff simulation but play a noteworthy part within the calibration of plant abdicate. The values of these parameters profoundly have an impact on the plants' water gathering and water stretch. On the other hand, BLAI, T_BASE, T_OPT, and BIO_E are critical parameters for agricultural items.

The yields of agrarian items within the SWAT demonstrate are based on the dry weight of agricultural items; in other words, the sum of water in rural items within the yields of the SWAT show is diminished from them, and the dry weight of abdicating appears as the yield within the show (Neitsch et al., 2011). Be that as it may, when the agricultural items are collected, they are damp, and the sum of water in each item should be included in the show's yields to illuminate this issue. In this manner, agreeing to the information accessible at the USDA Base (https:/ndb.nal.usda.gov/ndb/foods), the sum of water found in each item was gotten and applied yields of the demonstrate. These changes are made as takes after. Moreover, Table (2) appears the rate of water accessible in each rural item. In Eq. 1, the calculation of the edit surrender of agricultural commodities appears.

Real Crop yield = Crop yield (model) + Crop yield (model) × Water content (1)

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Table 2- Water content within the crops

crop	Water content		Source
	minimum	maximum	
Winter Wheat	0.1	0.15	https:/ndb.nal.usda.gov/ndb/foods
Spring Wheat	0.1	0.15	
Tomato	0.85	0.95	
Almond	0.03	0.07	
Apple	0.75	0.85	

Table 3- Evaluation criteria used in research

Index	Equation	Range of index	Eq.
NSE	$NSE = 1 - [\frac{\sum_1^N (O_i - M_i)^2}{\sum_1^N (O_i - M_{avg})^2}]$	-∞ - 1	2
R^2	$[\frac{\sum_1^N (O_i - O_{avg})(M_i - M_{avg})}{\sqrt{\sum_1^N (O_i - O_{avg})^2}\sqrt{(M_i - M_{avg})^2}}]$	0 - 1	3

Sensitivity analysis evaluates the model quantitatively and qualitatively from the input values drawn from different sources. It is considered as a prerequisite for the construction of diagnostic and forecasting models in each case study.

Abbaspour (2009) also recommends evaluating the sensitivity of the model before calibration. Therefore, before calibrating the model, the sensitivity of flow parameters was ranked first. Automatic optimization of model parameters from the ability to intelligently replace with physical knowledge and insight resulting from the effects of model parameters cannot intelligently replace knowledge and physical understanding of the impact of system parameters, so before optimizing the model parameters, the sensitivity of each was ranked, and more essential parameters were selected. Sensitivity analysis was performed by keeping all parameters constant and changing the desired parameters.

In this consider, ArcSWAT2012 is utilized as a visual interface to plan a SWAT show inside ESRI ArcMap 10.3. To set up the demonstration, a 10 m computerized rise outline, the worldwide soil outline delivered by the FAO (Fischer et al., 2008) with a determination of 10 km and the GLCC (https://lta.cr.usgs.gov/glcc/globe_int) arrive utilize a method with the resolution of 1 km are given. Potential evapotranspiration calculation was carried out using the Hargreaves strategy that, as there were needs day by day at least and most extreme temperatures as input.

According to Fig. (3), the watershed test case was separated into 11 sub-basins, 466 HRUs. The administrative information counting sum of the water system for developed crops within the current trimming design (including spring wheat, winter wheat, tomato, almond, and apple) and rural unit fertilizers was joined into the model. In expansion, watching the most significant and least temperatures every day was utilized from eight existing meteorological stations inside the watershed.

Calibration and instability examination of the results created by the show was executed utilizing the SUFI2 calculation within the SWAT-CUP program (Abbaspour et al., 2008). This strategy licenses setting ranges for the parameters of intrigued and a while later running numerous recreations with different parameter sets examined by Latin hypercube. In this ponder, Nash-Sutcliffe Productivity (NSE) objective work was relegated, and the program returned the extend of anticipated instability within 95% of the most excellent reenactments. Encourage, to compare the execution of models, the measurable files of NSE Eq. (2), and R2 Eq. (3) was utilized. Table (3) illustrates the conditions used to compute each objective metric, where: N is the number of months; Oi is observed discharge for the month i; Mi is the calculated discharge for the month i; and Ma,

$Oavg$ are average of calculated and observed discharge respectively.

Results

In recent decades, various models have been designed to quantitatively and qualitatively estimate surface and groundwater flows. Still, physical and continuous models are more important because of their adaptation to the theoretical properties of the basin. Therefore, in the present study, the SWAT model, a physical model with the ability to use time series, was selected to predict runoff and study the trend of surface, subsurface, and underground flow changes.

In this study, the basin hydrology processes were simulated to investigate these parameters' effects on the hydrological components of the Bakhtegan watershed by using the semi-distributed SWAT model. Simulation results were calibrated in SWAT CUP software.

Based on the model's sensitivity analysis results, 19 parameters were identified as the most sensitive parameters, the results of which are presented in Table (4). The infiltration curve parameter in medium humidity conditions (CN2) has the most significant effect on the basin's outflow. After CN2, the parameters ESCO and SOL_AWC, the coefficient of compensation of soil evaporation, and the average water use in the surface layer, respectively, are in the following ranks. After the sensitivity analysis stage, with SWAT CUP software and monthly discharge statistics in Chamriz station, the model was calibrated and validated. An important point was noted; these steps be performed separately for years close to the user map under review. For example, for calibration of the model, based on land use map of 2006. This view was based on the approach used by Koch (2011). Finally, the model was evaluated using two coefficients of explanation coefficient (R^2) and Nash-Sutcliffe coefficient (N-S), the results of which are shown in Table (4).

As mentioned for the hydrologic modeling, 2004-2006 was determined as the warm-up period. The period of 2006-2012 was calibrated, and Fig. (4) shows the simulated is very Accurate because the simulation and observed data are very close.

Table (5) shows the statistical indices of NSE, R^2, MSE, KGE for calibration.

As mentioned for the hydrologic modeling, 2013 was chosen for the validation (Fig. 5), and because of the accurate calibration, the validation is accurate as well.

Table (6) shows the statistical indices of NSE, R^2, MSE, and KGE for validation.

Table 4– Model sensitivity analysis results

Range of parameter		Parameter	Range of parameter		Parameter
Max	min		Max	min	
70	0	GW_DELAY	98	35	CN2
1	0	RCHRG_DP	1	0	ESCO
25	0	GWHT	0.5	-0.5	SOL_AWC
1	0	TIMP	5	-5	SFTMP
100	0	REVAPMN	5	-5	SMTMP
5000	1000	DEEPST	1	0	EPCO
0.4	-0.4	SOL_BD	1	0	ALPHA_BF
500	0	GWQMN	150	10	SLSUBBSN
0.8	0	OV_N	0.3	0	CH_N2
	-		10	0	MSK_CO2

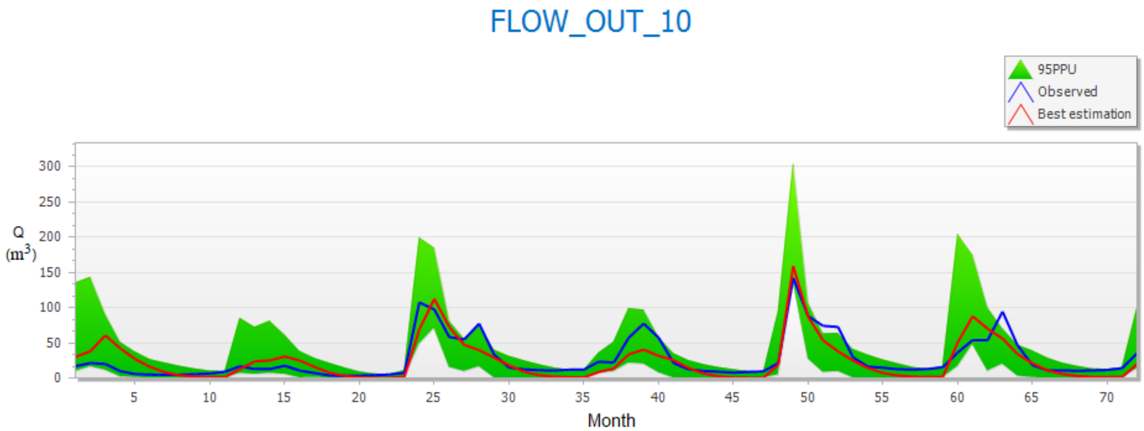

Fig 4- The period of calibration

Table 5- The statistical indices of NSE, R^2, MSE, KGE

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	Mean-sim (Mean-obs)
FLOW-OUT-10	0.94	1.15	0.74	0.71	0.635	2.50E+02	4.90E+01	10.9	0.82	0.54	24.17(27.14)

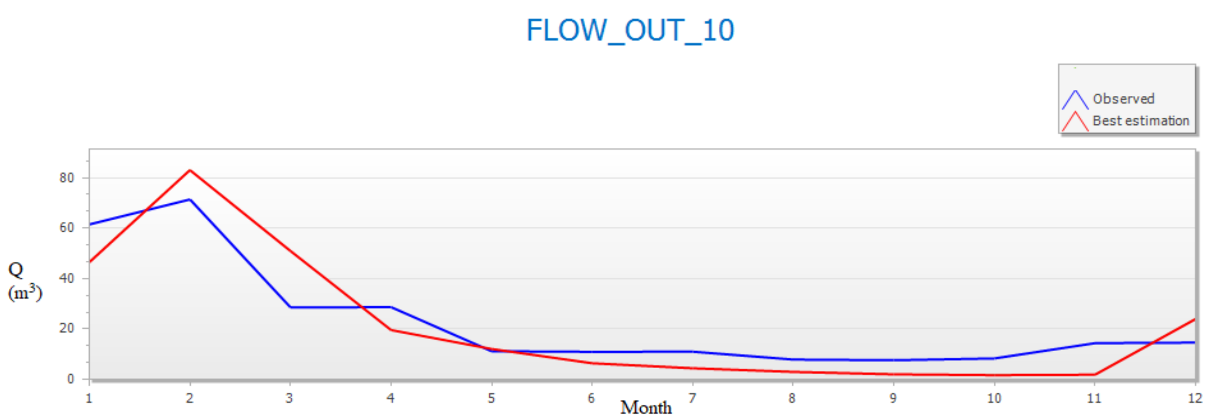

Fig 5-The period of validation

Table 6- The statistical indices of NSE, R^2, MSE, KGE

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	Mean-sim (Mean-obs)
FLOW-OUT-10	0.08	0	0.83	0.74	0.758	1.10E+02	7.10E+01	7.5	0.77	0.51	21.27(22.98)

Therefore, it has been found that the run model is very accurate so that it shows that the data (Land use, Soil map, slope map, Precipitation, and Temperature) used for the setup of the swat model was accurate.

Conclusion

Runoff prediction is a significant component of watershed hydrologic modeling, whether for resource conservation or environmental protection. Advances in continuous time, distributed parameter hydrologic modeling, and its integration with Geographical Information Systems (GIS) have led to powerful tools for predicting runoff from watersheds. However, the same advances have provided modelers and users the complex task of appropriately parameterizing the watershed by these models' large input requirements. This paper has described the essential parameterization issues involved when predicting watershed stream runoff using SWAT (Soil and Water Assessment Tool). Understanding these issues is expected to result in improved SWAT runoff prediction performance.

Hydrology's essential parameters such as land use, soil map, slope map, precipitation, and temperatures that significantly impact hydrology and the watershed water resources should be considered in the modeling. In this study, to investigate the effects of these parameters on hydrological components of the Bakhtegan watershed, located in the longitude of N 30°59' to 30°14' and latitude of E 51°42' to 52°54'by using the semi-distributed SWAT model, the basin hydrology processes were simulated. Simulation results were calibrated in SWAT CUP software. After calibration to validate the model, validation was performed, as mentioned in section 3. This study's Nash-Sutcliffe and the R2 coefficient were perfect, similar to Hosseini et al. (2015).

Adequately capturing watersheds' spatial variability has long been an accepted prerequisite for using these hydrologic models to improve runoff prediction. This study has shown that for the selected watershed in Bakhtegan, the adoption of hydrologic response units (HRUs) is sufficient to capture this variability. Subdividing the watershed into spatially referenced and individually routed subbasins or grid elements may be required only for the following scenarios: in the presence of site-specific water impoundments such as reservoirs or ponds, for large basins, when significant channel abstractions or losses are expected, and in cases where detailed visualization of the spatial distribution of an output parameter such as runoff or erosion is desired.

This study has also shown that improved runoff predictions are obtained through relatively easy and automated return flow contribution adjustments to streamflow and curve numbers with time and space. Illustrative simulation runs were presented using the actual watershed in the Bakhtegan watershed. Using these parameterization approaches, it was shown that SWAT stream runoff prediction could be improved for watersheds with areas under extensive subsurface drainage. However, it is predicted that better performance may be expected if SWAT is extended to directly handle the physical processes that govern water movement to subsurface drains. In general, this study's results provide practical examples regarding how SWAT stream runoff prediction may be improved, particularly for modeling ungagged watersheds wherein observed data for calibration is not available.

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