ORIGINAL PAPER

Simulation of water balance equation components using SWAT model in Samalqan Watershed (Iran)

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Abstract

The disparate temporal and local distribution of freshwater and the rapid growth of the population in recent decades have led to problems in providing water resources for various applications. Hence, the supply of water in many countries such as Iran has become one of the most important challenges of the present century. Modern mathematical models have been developed for studying the complex hydrological processes of a watershed. The application of conceptual hydrological models is an important issue in watersheds for researchers, especially in arid and semiarid regions. The hydrological behaviors are complicated in such watersheds, and their calibration is more difficult. In this research, the conceptual and semidistributed SWAT model is used for Samalqan watershed, Iran, with 1148 km^2 area. Streamflow simulation is considered for 13 years. Samalqan watershed modeling led to 22 subbasins and 413 hydrologic response units. Water balance components have been computed, the results have been calibrated with the SUfl2 approach in the SWAT-CUP program, and finally, the performance of the model is evaluated. The sensitivity analysis was conducted using 26 SWAT parameters. The most sensitive parameters were CN2 (moisture condition II curve number), GWQMN (threshold water level in shallow aquifer for base flow), GW_Delay (delay time for aquifer recharge), GW_REVAP (Revap coefficient), and ESCO (Soil evaporation compensation coefficient). The model was calibrated from 2004 to 2012 and validated from 2012 to 2014. The coefficient of determination (R^2) and Nash and Sutcliffe efficiency (NSE), On monthly basis, were between 0.60–0.80 and 0.80–0.95 respectively, for calibration, and 0.70–0.90 and 0.70–0.80, respectively, for validation periods, which indicates that the model results are satisfactory. Results show that the SWAT model can be used efficiently in semiarid regions to support water management policies and development of sustainable water management strategies. Due to the arid and semiarid climate of Iran and water resources constraints, the need for modeling is clear. It can be concluded that determination of the existing water potential is necessary for water planning and management of water resources in the watershed.

Keywords SWAT model · SUFI2 · Streamflow · Water balance · Iran · Samalqan

Introduction

Water is an essential element for the survival of living things. Many zones in the world face scarcity of freshwater. Thus, the availability and the sustainable use of the water resources become the core of the local and national strategies and politics in these regions. So hydrological models are important tools for planning the sustainable use of water resources to meet various demands.

Iran is one of the world's most arid countries, with an average rainfall of under 250 mm a year. Application of models has become an indispensable tool for understanding the hydrological processes occurring at the watershed scale as the models provide an accurate estimate of components of water balance. To deal with water management issues, one must analyze and quantify the different elements of hydrologic processes taking place within the area. Obviously, this analysis must be carried out on a watershed basis because all these processes are taking place within individual microwatersheds. Hydrological processes and their local scattering have always direct relation to weather, topography, geology, and land use of watershed in addition to the impact of human activities. A

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watershed is comprised of land areas and channels and may have lakes, ponds, or other water bodies. The flow of water on land areas occurs not only over the surface but also below it in the unsaturated zone and further below in the saturated zone, (Singh and Frevert 2002). The use of a watershed model to simulate these processes plays a fundamental role in addressing a range of water resources and environmental and social problems. One of these hydrological models is SWAT, which is tested in various world climates from arid and semiarid regions (Rafiei Emam et al. 2015) to humid and tropical areas (Nguyen and Kappas 2015). SWAT model has been adjudged by researches as computationally efficient in its prediction; it has a reliability which confirmed in several areas around the world. This model was applied in large scale to evaluate the hydrological processes in a mountain environment of Upper Indus River Basin by Khan et al. (2014) and in other regions in Asia by Nasrin et al. (2013) and Cindy and Koichiro (2012). It was tested and used in many regions of Africa by Fadil et al. (2011), Ashagre (2009) and Schuol et al. (2008). It also applied to simulate St. Joseph River watershed in USA by Kieser et al. (2005). Schuol et al. (2008) simulated hydrology of the entire Africa with SWAT in a single project and calculated water resources in a subbasin spatial resolution and monthly time intervals. Faramarzi et al. (2009) simulated hydrology and crop yield for Iran with SWAT. In a subsequent work, Faramarzi et al. (2013) used the African model to study the impact of climate change in Africa. Gan and Luo (2013) used a nonlinear reservoir model to calculate base flow in glacier and snowmelt-dominated basins. Similarly, Wang and Brubaker (2014) modified the linear reservoir model, which is used to calculate groundwater flow, to a nonlinear reservoir model in a Karst area. Pfannerstill et al. (2014) found out that the SWAT model performed poorly for low flow periods in North German lowlands. Phuong et al. (2014) evaluated the surface runoff and soil erosion in a regional area in Vietnam. Qi et al. (2017) proposed an energy balance module for SWAT to improve the simulation accuracy for snowmelt. Chen et al. (2018) modified the SWAT autoirrigation functions to improve the simulation accuracy of agricultural irrigation management. Tsuchiya et al. (2018) proposed an enhanced paddy simulation module to improve the simulation accuracy of paddy water balance.

Considering the groundwater discharge and the drop in water level in Samalqan plain, it is necessary to study and monitor the aquifer status. Since one of the most important hydrological factors involved in aquifer recharge is rainfall, a model is needed to estimate surface runoff and groundwater percolation, considering all meteorological, hydrological, and geological factors. Therefore, the SWAT model was used to estimate the parameters of the water balance equation such as deep percolation in the basin. So that, this parameter can be entered into different time steps in the MODFLOW groundwater flow model, and by linking the surface and groundwater models, the fluctuations of groundwater level, and the drop in water table were estimated. Due to the drought and negative water balance in Samalqan plain and according to that, there is no any study on estimation of water balance in the region, the main objectives of this study are to compute the runoff of the Samalqan river basin using SWAT model, calibrate, and validate the model using observed data and estimate parameters of water balance equation and groundwater recharge in order to water management in the watershed.

Material and methods

Description of the study area

The Samalqan river watershed is located between 37° 21′ to 37° 39′ north latitude and 56° 25′ to 57° 06′ east longitude with semiarid to arid climate in Atrak basin, North Khorasan Province, Iran (Fig. 1). The total geographical area is 1148 km^2 that consist of 927 km^2 mountainous terrains and about 221 km^2 plain and aquifer. The maximum elevation is in Korkhod Mountains (2680 m above sea level), and the minimum elevation is at the outlet of watershed (Darband Samalqan) at 600 m above sea level. The average annual precipitation is 465 mm, but this varies considerably from 1 year to another. The mean annual temperature is 11.1 °C, and the annual evapotranspiration is about 1132 mm. The Samalqan River is the mainstream of the area that flows from the southwest to the northeast of the plain. It has two branches, Shirabad and Darkesh Rivers.

The hydrologic simulator (SWAT)

SWAT, soil water assessment tool, is a physical-based, semi-distributed, continuous time, and a river basin or watershed, scale model that operating on daily time step and uses a command structure for routing runoff and chemical through watershed. It developed by Agricultural Research Services of United States Department of Agricultural, to predict the impact of land management practices on water, sediment, and agriculture chemical yields in large and complex watersheds with varying soil, land use, and management conditions over long periods of time (Arnold et al. 2012). As a physical-based model, SWAT uses hydrological response units (HRUs) to describe spatial heterogeneity in terms of land use, soil types, and slope within a watershed. In order to simulate hydrological processes in a watershed, SWAT divides the watershed into subbasins based upon drainage areas of the tributaries. The subbasins are further divided into smaller spatial modeling units known as HRUs. The main advantage of SWAT is the capability to run simulations for large watersheds without

Fig. 1 Location of the
experimental field in the
Samalqan catchment
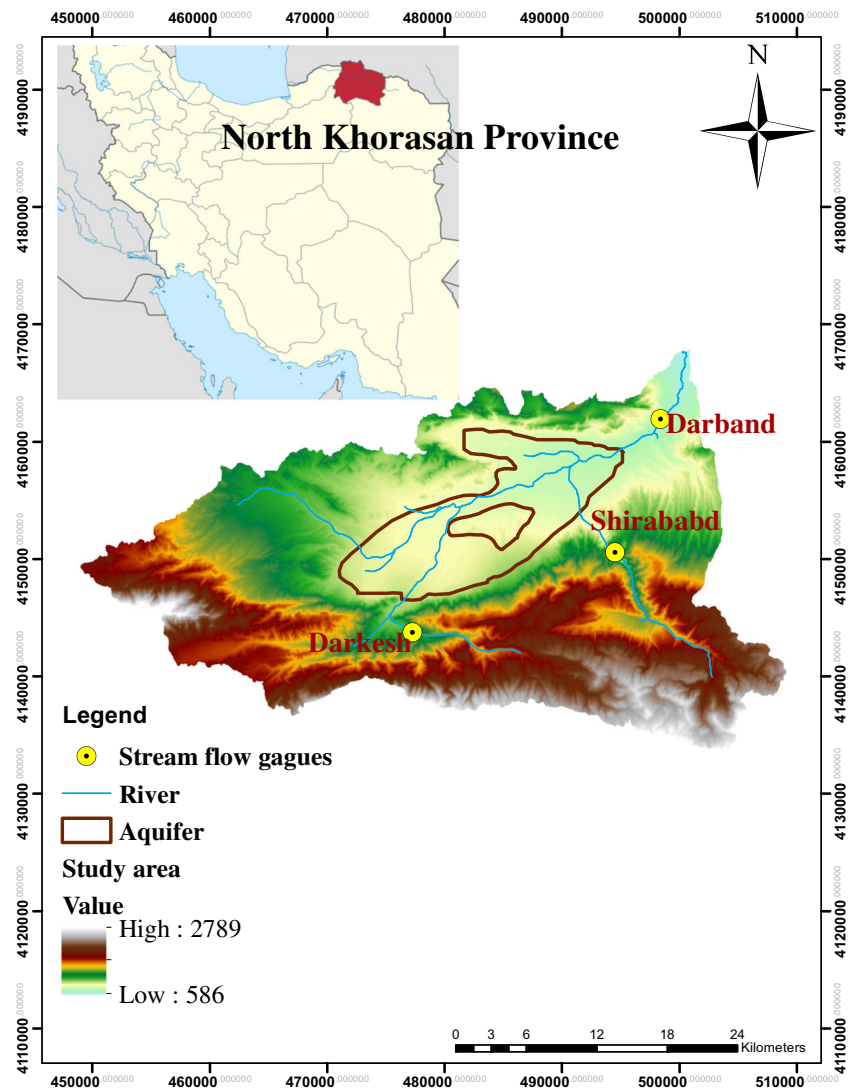
extensive monitoring data and the capacity to predict changes
in hydrological parameters under different management prac-
tices and physical environmental factors (Gassman et al. 2007;
Daloglu et al. 2014). For simulation, SWAT needs digital
elevation model, land use and land cover map, soil data, and
climate data of the study area. These data are used as an input
for the analysis of hydrological simulation of surface runoff
and groundwater recharge. SWAT splits hydrological simula-
tions of a watershed into two major phases: the land phase and
the routing phase. The land phase of the hydrological cycle
controls the amount of water, sediment, nutrient, and pesticide
loadings to the main channel in each subbasins. While the
routing phase considers the movement of water, sediment,
and agricultural chemicals through the channel network to
the watershed outlet. The land phase of the hydrologic cycle
is modeled in SWAT based on the water balance equation
(Arnold et al. 2012; Gassman et al. 2007):

$$SW_t = SW_o + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \quad (1)$$

where, SW_t is the final soil water content (mm); SW_o is
the initial water content (mm).; t is the time (days); R_{day}
is the amount of precipitation on day i (mm); Q_{sur} is the
amount of surface runoff on day i (mm); E_a is the
amount of evapotranspiration on day i (mm); W_{seep} is
the amount of water entering the vadose zone from the
soil profile on day i (mm); Q_{gw}: the amount of return
flow on day i (mm). Surface runoff refers to the portion
of rain water that is not lost to interception, infiltration,
and evapotranspiration; surface runoff occurs whenever
the rate of precipitation exceeds the rate of infiltration.
SWAT offers two methods for estimating the surface
runoff, the Soil Conservation Service (SCS) curve num-
ber method or the Green and Ampt infiltration method
(Green and Ampt 1911). The Green and Ampt method
needs subdaily time step rainfall which made it difficult
to be used for this study due to unavailability of
subdaily rainfall data. Therefore, the SCS curve number
method was adopted for this study. The general

equation for the SCS curve number method is given in the following equation:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \qquad (2)$$

where, Q_{surf} is the accumulated runoff or rainfall excess (mm); R_{day} is the rainfall depth for the day (mm H2O); S is retention parameter (mm H2O). The retention parameter varies spatially due to changes with land surface features such as soils, land use, slope, and management practices. This parameter can also be affected temporally due to changes in soil water content. It is mathematically expressed as Eq. (3):

$$S = 25.4 \left(\frac{1000}{CN} - 10 \right) \qquad (3)$$

where, CN is the curve number for the day and its value is the function of land use practice, soil permeability, and soil hydrologic group. The initial abstraction, I_a, is commonly approximated as 0.2S and the Eq. (4) becomes:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad (4)$$

where Ia is the initial abstraction which includes surface storage, interception, and infiltration prior to runoff (mm H2O).

For the definition of hydrological groups, the model uses the US Natural Resource Conservation Service (NRCS) classification. The classification defines a hydrological group as a group of soils having similar runoff potential under similar storm and land cover conditions. Thus, soils are classified into four hydrologic groups (A, B, C, and D) based on infiltration which represents high, moderate, slow, and very slow infiltration rates, respectively. The lateral flow in SWAT model estimates using the kinetic reservoir routing based on the degree and length of slope and saturated hydraulic conductivity (Sloan et al. 1983). There are two methods for calculating the surface retention coefficient in SWAT model. The first method in which the surface retention coefficient changes with moisture content in the soil profile, and an alternative method in which the surface retention coefficient changes with the cumulative evapotranspiration. The SWAT model calculates evaporation from soil and plant separately. According to available information, potential evapotranspiration can be calculated by Penman-Monteith, Priestley-Taylor, and Hargreaves method. The information required for the Penman-Monteith method is solar radiation, air temperature, wind speed, and relative humidity. In Hargreaves method only air temperature information is needed, and in Priestley-Taylor method, radiation information, air temperature, and relative humidity are needed. Therefore, according to the available

information in the region, the Hargreaves method was used. Figure 2 shows the hydrological system with SWAT model.

Creation of database

In this study, we had used the Arc SWAT graphical user interface to manipulate and execute the major functions of SWAT model from the ArcGIS tool. The first step in using SWAT model is to delineate the studied watershed and then divide it into multiple subbasins based on digital elevation model (DEM) and the outlets generated by the intersection of reaches or those specified by the user. Thereafter, each subbasin is subdivided into homogeneous areas called hydrologic response units (HRUs) that GIS derives from the overlaying of slope, land use, and soil layers. Figure 3 gives a global view of SWAT model components including the spatial and GIS parts. The basic spatial data needed for the Arc SWAT interface are DEM, soil type, and land use.

Model setup

Watershed delineation

The watershed delineation process consists of five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets, selection, definition, and calculation of subbasin parameters. The DEM was used to delineate the watershed and subbasins as the drainage surfaces, stream network, and longest reaches. The topographic parameters such as terrain slope, channel slope, or reach length were also derived from the DEM. In this study, based on the mapping of the topography, a new version of the SRTM (the shuttle radar topography mission) data, with a cell size of 30 m, due to the lower root mean square error, was used for physiographic analysis.

The stream definition and the size of subbasins were carefully determined by selecting threshold area or minimum drainage area required to form the origin of the streams. The Samalqan watershed was delineated into 22 subbasins during the watershed delineation process (Fig. 4).

Hydrologic response unit analysis

The subbasins were divided into 413 HRUs by assigning the threshold values of land use and land cover, soil, and slope percentage. Land use, soil, and slope characterization for the watershed were performed using commands from the HRU analysis menu on the Arc SWAT toolbar. These tools allowed loading land use and soil maps which are in raster format in to the current project, evaluates slope characteristics, and determining the land use/soil/slope class combinations in delineated subbasins (Fig. 5). The spatial information layers of the land use area of Salmaqan study area, prepared by the
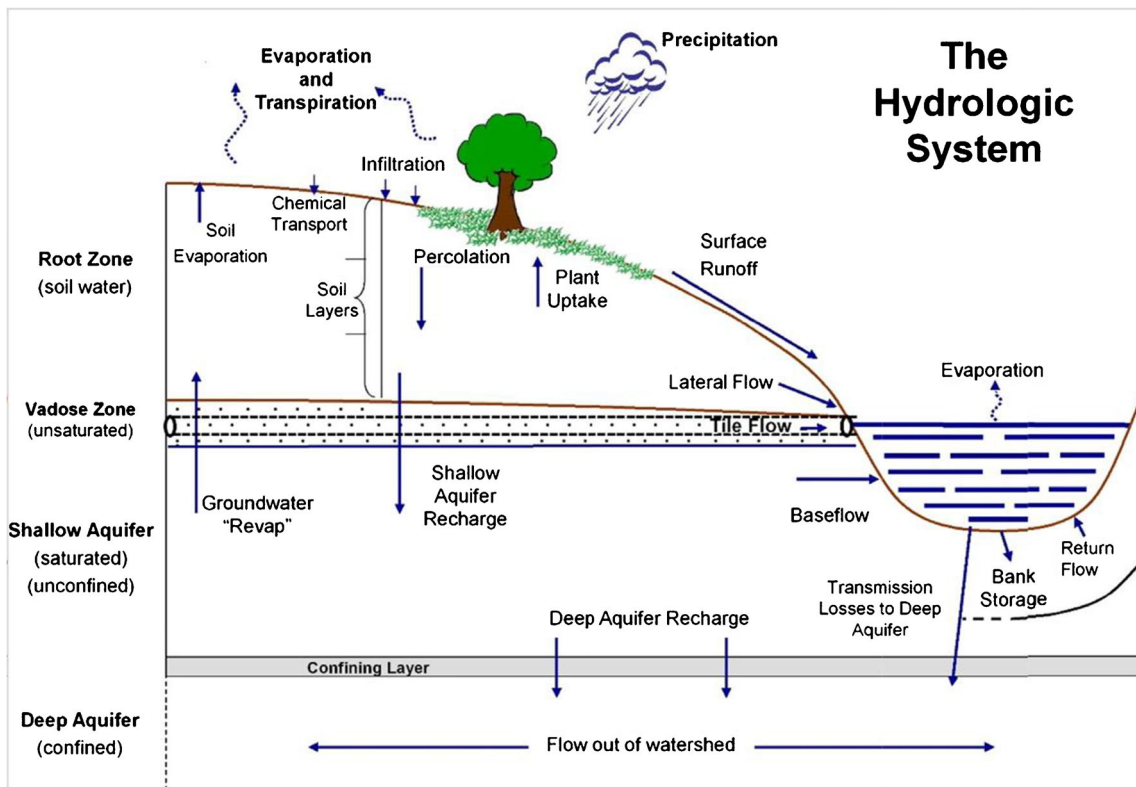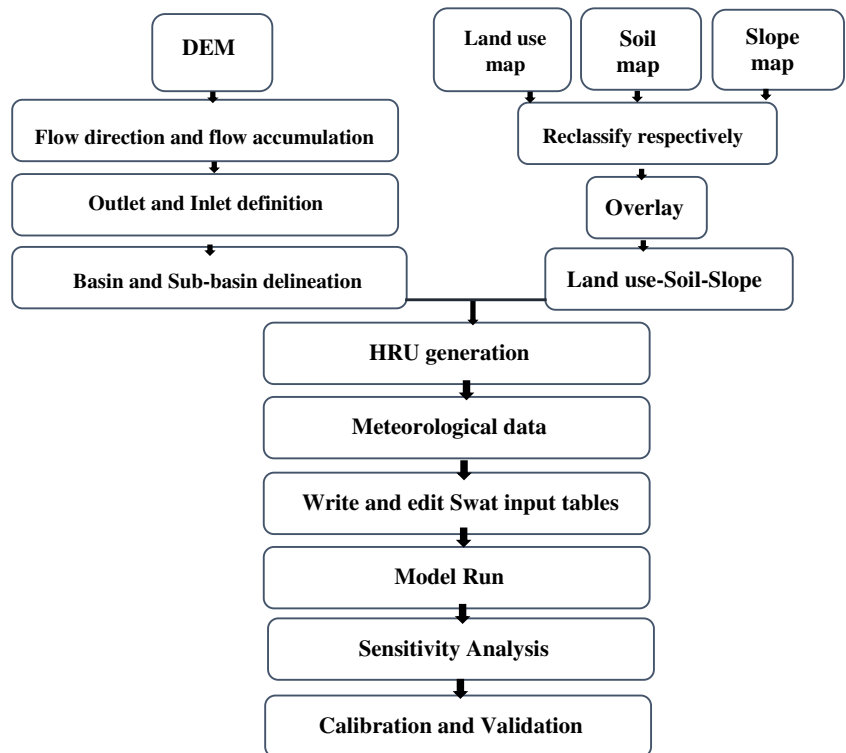
Fig. 2 Schematic of the hydrological cycle and SWAT simulation processes (Neitsch et al. 2005)

Department of Natural Resources of North Khorasan Province, has been verified using remote sensing data and Landsat satellite series images. The land use map was extracted through the processing of satellite Landsat image that has a spatial resolution of 30 m. The supervised classification and the photointerpretation techniques were used to

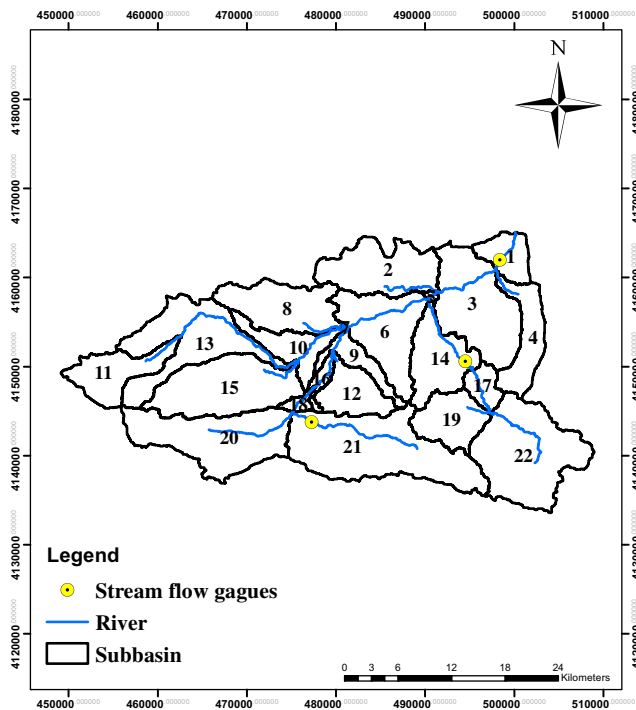Fig. 3 Model setup diagram for SWAT model

Fig. 4 The Samalqan catchment delineated into subbasins with Arc SWAT interface

simulated by the model. The SWAT model contains weather generator model called WXGEN (Sharpley and Williams 1990). It is used to generate climatic data or to fill missing data using monthly statistics which is calculated from existing daily data. From the values of weather generator parameters, the water generator (WGN) generates the climate variables that said earlier. In order to use the WGN to generate daily meteorological data, several meteorological stations, which have the most complete weather parameters, should be used. These parameters calculated for each month at the station and finally entered as a file called User WGN in the model database. The Samalqan watershed includes several weather stations that measure daily precipitation and temperature. These data were collected from 4 rain gauges (Darkesh, Darband Samalqan, Shirabad, and Resalat) and one station (Resalat) for measuring daily minimum and maximum temperature for simulation period (2002–2014). Other climatic parameters are simulated by the model using the weather generator based on the data of the nearest synoptic station (which has the role of data generator). In this study, the synoptic stations of Mashhad and Bojnourd were used.

Model simulation

After preparing data files and completing all model inputs, the model is ready for simulation. The simulation is done for a period of 13 years from 2002 to 2014. The first 2 years of which was used as a warmup period, and the simulation was then used for sensitivity analysis of hydrologic parameters and for calibration of the model. The sensitivity analysis was made using a built-in SWAT sensitivity analysis tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) (Van Griensven et al. 2006). Table 3 shows the information about three stream flow gauges in the watershed that used for model simulation. A recent version of SWAT-CUP includes several calibration and uncertainty analysis techniques: SUFI-2 (sequential uncertainty fitting), GLUE (generalized likelihood uncertainty estimation), PARASOL (parameter solution), MCMC (Markov Chain Monte Carlo), and PSO (particle swarm optimization). SUFI-2 proved to be a very efficient optimization algorithm and could be run with the smallest number of models runs to achieve good prediction uncertainty ranges. This technique considers parameter uncertainty for all sources of uncertainties (both in input and observed data, as well as in the conceptual model). The degree to which all uncertainties are accounted for is quantified by the p factor. It is the percentage of measured data bracketed by the 95-percentage prediction uncertainty (95PPU) (Abbaspour 2009, 2011a, b). Previous studies have shown that SUFI-2 program is very efficient in calibration of SWAT for small watersheds (Abbaspour et al. 2007b).

derive and distinguish the most present land use classes in Samalqan catchment. Each land cover in the SWAT model is entered as a four-letter code in the layer information table. Eight major classes are so identified in Table 1. The dominant categories are range pasture (36.3%), forest (28%), dry land and crop land (24%), and agriculture (2.7%). The urbanized areas represent just 0.8% of the watershed. Soil data is one of the most important inputs for each hydrological model. For preparing the map of soil units in the region, the topographic, geology, and land use maps have been used and overlapped to each other. In order to analysis of soil properties such as soil texture and soil morphology, global remote sensing data (ISRIC database) and existing soil reports in the area have been used. Finally, 17 soil units were identified in the study area and used in the model as a raster with a spatial resolution of 30 m. The general characteristics of these units are presented in Table 2.

Weather generator

The climate of the basin provides the amount of energy and water that controls the basin's water balance and highlights the relative importance of the various components of the hydrological cycle. The climate variables required in the SWAT model are: daily precipitation, daily maximum and minimum temperature, daily solar radiation, mean daily wind speed, and mean daily relative humidity. These values have either entered the model as input data or
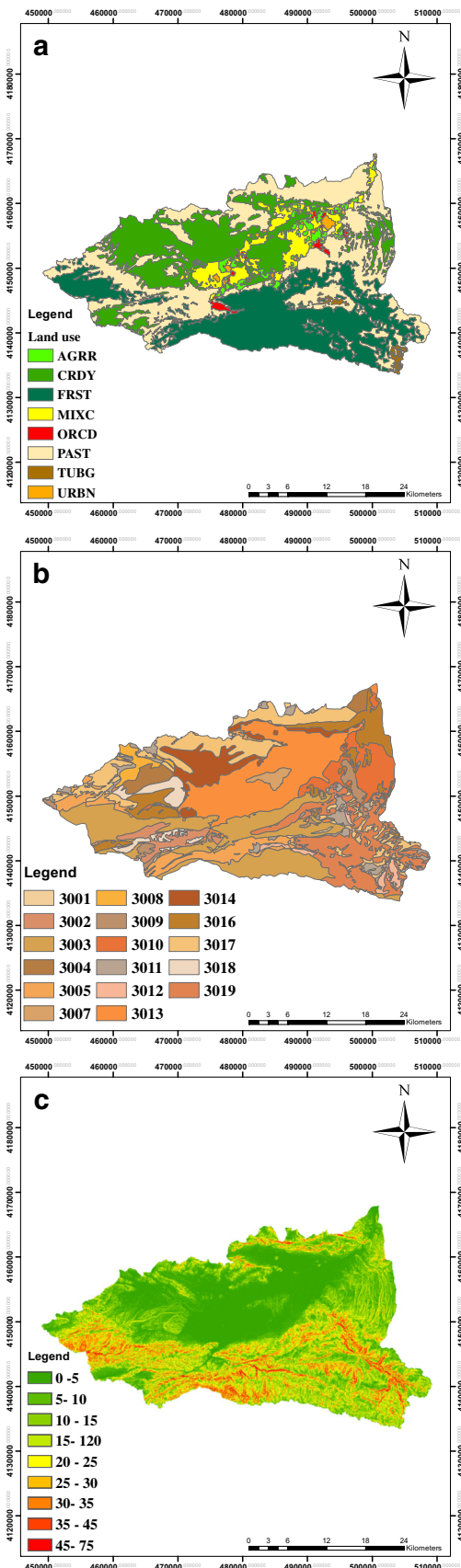
Fig. 5 GIS layers used in SWAT model for create HRU. **a** Land-use map, **b** soil map, **c** slope map

Model performed 5 times and repeated 500 times each time of calibration. In such case, the calibration process becomes complex and computationally extensive. Hence, parameter reduction by filtering out the less influential ones is essential before calibration. The sensitivity analysis is so used to identify and rank the most responsive hydrological parameters that have significant impact on specific model output which is the outflow in this case (Saltelli et al. 2000).

Model efficiency

There are many methods to assess and evaluate the accuracy of results produced by the model. The calibration and the validation were carried out using the coefficient of determination (R^2) and three commonly statistic coefficients, (Moriasi et al. 2007) and (Fadil et al. 2011), these statistic operators are Nash–Sutcliffe efficiency index (NSE), percent bias (PBIAS), and RMSE-observations standard deviation ratio (RSR).

Coefficient of determination (R^2)

It is a good method to signify the consistency among observed and simulated data by following a best fit line. It ranges from zero to 1.0 with higher values indicating less error variance, and values greater than 0.50 are considered acceptable, (Santhi et al. 2001) and (Van Liew et al. 2007)

$$R^2 = \frac{\left[\sum_{i=1}^{n} \left(O_i - \overline{O} \right) \left(P_i - \overline{P} \right) \right]}{\sum_{i=1}^{n} \left[\left(O_i - \overline{O} \right) \sum_{i=1}^{n} \left(P_i - \overline{P} \right)^2 \right]} \qquad (5)$$

Nash–Sutcliffe efficiency

NSE is a normalized statistic method used for the prediction of relative amount of noise compared with information. It is presented by Nash and Sutcliffe (1970) and is calculated from the following equation:

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n} \left(P_i - O_i \right)^2}{\sum_{i=1}^{n} \left(O_i - \overline{O} \right)^2} \qquad (6)$$

where Pi is the ith observation (stream flow), O_i is the ith simulated value, $\overline{O}$ is the mean of observed data, and n is the total number of observations. NSE ranges from -1 to 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance. Generally, the model simulation is considered as satisfactory if NES > 0.5 (Moriasi et al. 2007).

Table 1 Land use classes used for Arc Swat in Samalqan catchment

Land use classes	SWAT classes	Area (Km²)	Watershed area %
Residential	URBN	9.21	0.80
Pasture	PAST	401.5	36.30
Agricultural land-row	AGRR	31.05	2.70
Mixed dryland /Irrigated crop land	MIXC	78.5	6.5
Dry land, crop land	CRDY	275.5	24.0
Orchard	ORCD	10.6	0.94
Forest-mixed	FRST	319.7	28.0
Bare ground tundra	TUBG	9.8	0.82

Percent bias

PBIAS measures the average tendency of the simulated values to be larger or smaller than their observed ones (Gupta et al. 1999). It is defined by the range − 10 to 10. The optimal value of PBIAS is 0.0, with low magnitude values indicating accurate model simulation. Negative values indicate overestimation bias, whereas positive values indicate model underestimation bias. The formula of these coefficients is:

$$\mathrm{PBIAS} = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{\mathrm{obs}} - Y_i^{\mathrm{sim}} \right) * 100}{\sum_{i=1}^{n} \left(Y_i^{\mathrm{obs}} \right)} \right] \quad (7)$$

RMSE-observations standard deviation ratio

Based on the recommendation by Singh et al. 2004, a model evaluation statistic, named the RMSE-observations standard deviation ratio (RSR) was developed. RSR is computed as shown in Eq. 8 as follows:

$$\mathrm{PSR} = \frac{\sqrt{\sum_{i=1}^{n} \left(Y_i^{\mathrm{obs}} - Y_i^{\mathrm{sim}} \right)^2}}{\sqrt{\sum_{i=1}^{n} \left(Y_i^{\mathrm{obs}} - Y_i^{\mathrm{mean}} \right)^2}} \quad (8)$$

The range from 0.0 which is the optimal value to 0.5 for RSR means a very good performance rating for both calibration and validation periods. The lower value of RSR indicates

Table 2 General characteristics of soil units in the study area

Permeability based on geological characteristic	Soil depth based on geological characteristic	Geological characteristic	Land use	Soil texture	Unit
High	High	Antelopes, young conifers, alluvial plains, young alluvial river	Pasture	Moderate	1
Moderate	Moderate	Conglomerate with poor consolidation	Forest	Moderate	2
Low	Low	Thick layer limestone, chert limestone, clayey limestone, and marl	Forest	Moderate	3
Low	Low	Shale	Orchard-agriculture	Moderate	4
Low	Low	Thick layer limestone, chert limestone, clayey limestone, and marl	TUBG	Moderate	5
high	high	Antelopes, young conifers, alluvial plains, young alluvial river	Orchard-agriculture	Moderate	6
Low	Low	Red marl and sandstone with layers of conglomerate	Pasture	Moderate	7
Moderate	high	Antelopes, old cones, alluvial plains	Orchard-agriculture	Moderate	8
Low	Low	Antelopes, old cones, alluvial plains	Orchard-agriculture	Moderate	9
Low	Moderate to high	Orbital insoluble limestone	Pasture	Moderate	10
Low	Moderate to high	Orbital insoluble limestone	Forest	Moderate	11
Low	Moderate to high	Orbital insoluble limestone	Orchard-agriculture	Moderate	12
Low	Low	Clay limestone, marl, sandstone and conglomerate, coarse sandstone and conglomerate	Orchard-agriculture	Moderate to strong	13
Moderate	Moderate	Conglomerate with poor consolidation	Pasture	Moderate	14
High	High	Antelopes, young conifers, alluvial plains, young alluvial river	Pasture	Moderate	15
High	High	Antelopes, young conifers, alluvial plains, young alluvial river	Orchard-agriculture	Moderate	16
Low	Moderate to high	Orbital insoluble limestone	Forest	Moderate	17

Table 3 List of stream flow gauges used for model simulation

Station. number	Station name	Subbasin number	Calibration	Validation	Long (deg)	Lat (deg)	Elev. (m)
1	Darkesh	21	2004-2012	2012-2014	56.98	37.60	671
2	Shirabad	16	2004-2012	2012-2014	56.74	37.44	1028
3	Darband	2	2004-2012	2012-2014	56.94	37.50	955

the lower of the root mean square error normalized by the observations standard deviation which indicates the rightness.

Results and discussion

Model calibration, validation, and sensitivity analysis are indispensable for simulation process, which are used to assess model prediction results. The details, discussions, and model evaluation are given as follows:

Sensitivity analysis

One of the most important steps in calibration of the distributed model, characterized by many parameters, is its correct parameterization, which as emphasized by Arnold et al. (2012) must be based on knowledge of the hydrologic processes in the system under study. Correct parameterization can result in faster and more accurate model calibration, with smaller prediction uncertainty. Parameter specification and estimation are two major stages of calibration (Soroshain and Gupta 1995). The goal of sensitivity analysis is to determine the cause-and-effect relation between model parameters and modeling results. In the case of watersheds, where no long-term data sets are available, the number of calibrated parameters should be minimized (Muleta and Nicklow 2005). Another advantage of sensitivity analysis is that it allows avoiding the problem with overparameterization of the model (Whittaker et al. 2010), which can lead to e.g. a loss of control over the model behavior (Krysanova and Arnold 2008).

In this study, at first, 50 parameters related to river flow were selected for calibration. Then, sensitivity analysis was done using SWAT-CUP program, and 25 sensitive parameters were identified for watershed (Abbaspour 2011a, b). Detailed descriptions of the parameters and the results of sensitivity analysis are presented in Table 4. According to the results of discharge simulations, the most sensitive parameters were

Table 4 Sensitive parameters used in SWAT calibration

Description	Parameter	t test	P value
SCS runoff curve number	CN2	0.868268	0.789496
Groundwater delay (days)	GW_DELAY	0.632664	0.845430
Baseflow alpha factor (days)	ALPHA_BF	0.001599	0.998729
Groundwater "revap" coefficient (mm/mm)	GW_REVAP	0.618648	0.558507
Deep aquifer percolation fraction (fraction)	RCHRG_DP	0.543964	0.588664
Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	GWQMN	0.754027	0.6515195
Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	REVAPMN	0.298753	0.766253
Depth from soil surface to bottom of layer (mm)	SOL_Z	0.563243	0.555449
Available water capacity of the soil layer (mm H2O/mm of soil)	SOL_AWC	0.377345	0.707369
Saturated hydraulic conductivity (mm/hr)	SOL_K	-0.230279	0.818728
Moist bulk density (gr/cm^3)	SOL_BD	-0.206112	0.837464
Soil evaporation compensation factor	ESCO	0.607811	0.000667
Plant uptake compensation factor	EPCO	-0.462828	0.645314
Temperature lapse rate(°C/km)	TLAPS	0.235823	0.814445
Precipitation lapse rate (mm/km)	PLAPS	0.092086	0.926963
Maximum canopy storage (mm)	CAN_MX	0.010209	0.991890
Effective hydraulic conductivity in main channel alluvium (mm/hr)	CH_K2	0.53786	0.0283187
Maximum melt rate for snow during year (mm/°C-day)	SMFMX	-0.337932	0.736700
Minimum melt rate for snow during the year (mm/°C-day)	SMFMN	0.681842	0.498199
Snowfall temperature (mm/°C-day)	SFTMP	-0.338667	0.736149
Snow melt base temperature (mm/°C-day)	SMTMP	0.532138	0.596773
Snow pack temperature lag factor (mm/°C-day)	TIMP	-0572314	0.569441
Initial depth of water in the shallow aquifer (mm)	SHALLST	0.339691	0.735382
Average slope length	SLSUBBSN	-0.152642	0.542125
Manning's "n" value for overland flow	OV_N	0.124285	0.549852

Table 5   Model evaluation statistics, calibration–validation periods

Station name	Coefficients											
	Calibrated period (2004–2012)						Validation Period (2012–2014)					
	P factor	R factor	R^2	NSE	PBIAS	PSR	P factor	R factor	R^2	NSE	PSR	PBIAS
Darband	0.82	0.90	0.92	0.85	− 3.0	0.58	0.80	0.87	0.85	0.80	0.55	− 2.8
Shirabad	0.75	0.78	0.85	0.80	2.5	0.50	0.78	0.75	0.80	0.78	0.52	1.5
Darkesh	0.72	0.76	0.82	0.75	3.8	0.48	0.75	0.70	0.76	0.72	0.46	2.6

CN2 (moisture condition II curve number), GWQMN (threshold water level in shallow aquifer for base flow), GW_Delay (delay time for aquifer recharge), GW_REVAP (revap coefficient), and ESCO (soil evaporation compensation coefficient).

Model calibration and validation

Physically based distributed watershed models should be calibrated before they are made use in the simulation of hydrologic processes. This is to reduce the uncertainty associated with the model prediction. In this study calibration was done by use of SUFI2 algorithm in SWAT-CUP (Abbaspour et al. 2007). Calibration was performed by comparing the simulated and observed surface runoff. Monitoring data were used only to verify the general range and magnitude of values simulated by the model. After achieving a reasonable runoff data, the same value of calibrated hydrological parameters was used for validation. The validation has been done thereafter to evaluate the performance of the model with calibrated parameters to simulate the hydrological functioning of the watershed over another time period that has not been used in the calibration phase. Flow calibration and validation were based on the observed flow data collected at the stream flow gauges in Samalqan watershed. The available measurements were used for comparison with the predicted results in order to test the SWAT

simulation efficiency. Calibration took place in monthly where outflow data are existed from 2004 to 2012, and then the parameters were validated from 2012 to 2014. The simulation results show a very good match with peak and low flow periods. The results suggest that the model can, very well, be used to predict the average annual values of river flow. The statistic evaluators showed a good correlation between the annually observed and simulated river discharge as follows. According to R^2 and NSE, the model results for both calibration and validation are satisfactory. The statistic evaluation of the model is summarized in Table 5. In this table, P factor is the percentage of observed data enveloped by our modeling result, the 95 ppu. R factor is the thickness of the 95 ppu envelop. In SUFI2, we try to get reasonable values of two these factors. While we would like to capture most of our observations in the 95 ppu envelop, we would at the same time like to have a small envelop. No hard numbers exist for what these two factors should be, like the fact that no hard numbers exist for R^2 or NSE. The larger they are, the better they are. For P factor, we suggested a value of > 70% for discharge, while having R factor of around 1 (Abbaspour et al. 2004, 2007). The model results of monthly flow which produced in SWAT-CUP are shown in Figs. 6, 7, and 8. Scatter plots of daily river discharge (Fig. 9) for stream flow gauges show a high correlation between observed and simulated data.

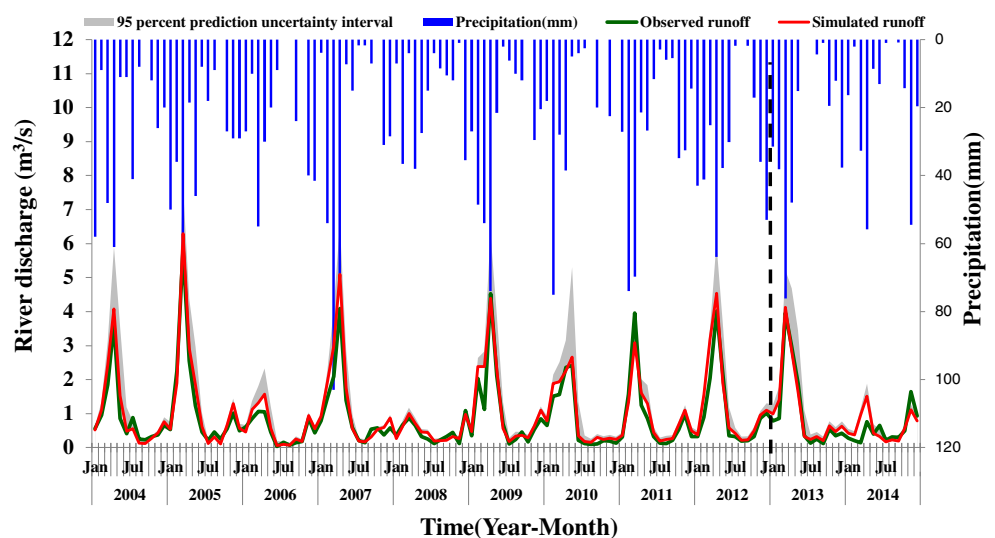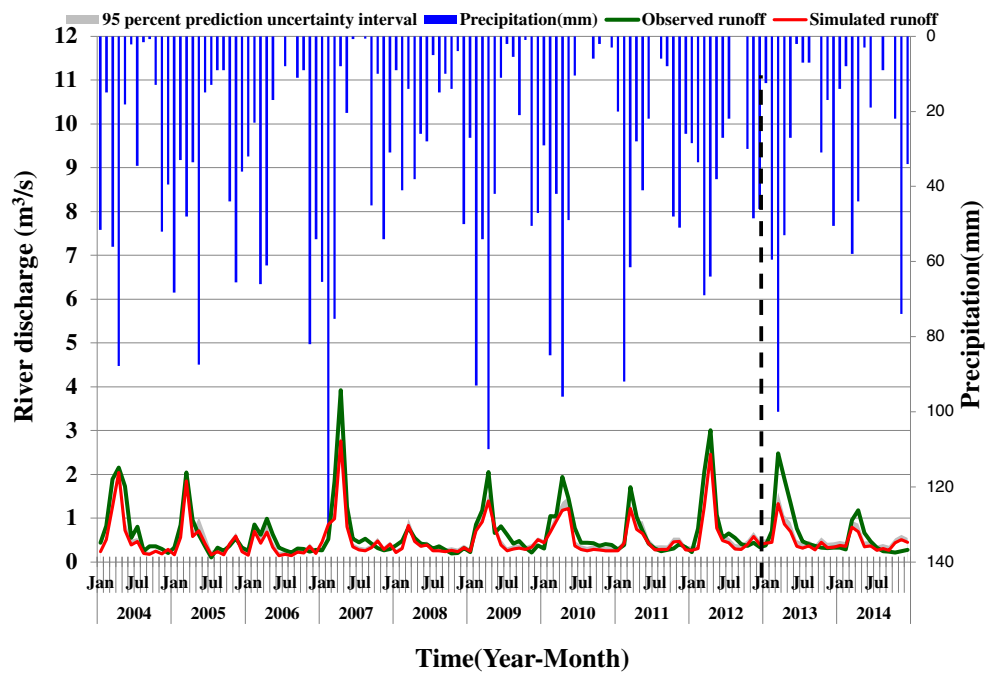**Fig. 6** Calibration and validation of the model by river discharge data (Darband station)

Fig. 7 Calibration and validation of the model by river discharge data (Shirabad station)
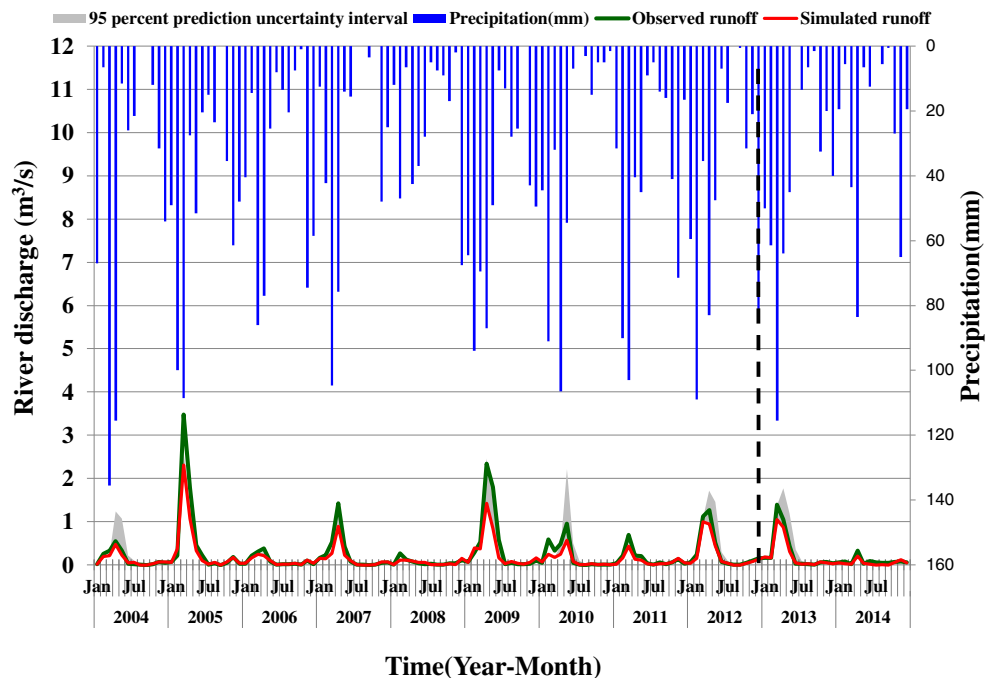

Water balance components

Utilization of both surface and ground water resources requires recognition of the behavior and amount of each resource in order to optimize the use of these resources and minimize damage to the environment. Currently, many plains in Iran have been declared forbidden plains, and it is not possible to extract more than groundwater, and some aquifers are being destroyed. Eliminating these dilemmas requires the supply of water balance, so that we can plan for sustainable

development. Calculation of water balance components requires the meteorological, hydrological, and hydrogeological data. In order to deal with water management issues, it is ideal to analyze and quantify the different elements of hydrological processes occurring within the area of interest. The SWAT model estimated other relevant water balance components in addition to the annual and monthly flow. The most important elements of water balance of a basin are precipitation, surface runoff, lateral flow, base flow, and evapotranspiration. Among these, all the variables, except precipitation, need

Fig. 8 Calibration and validation of the model by river discharge data (Darkesh station)
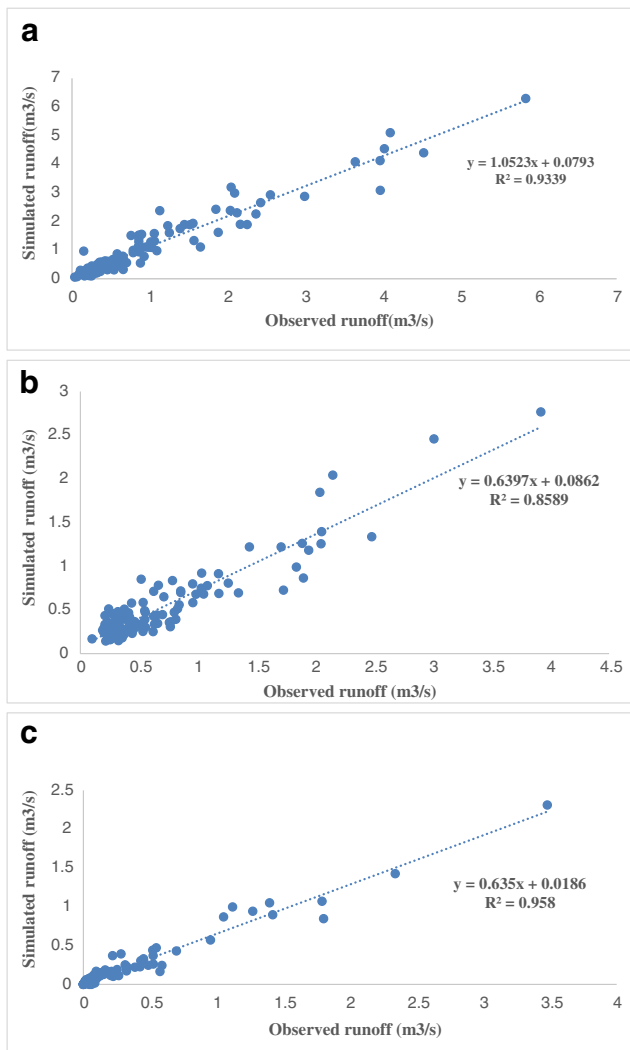
Fig. 9 Scatter plots of daily river discharge for stream flow gauge stations **a** Darband, **b** Shirabad, **c** Darkesh

prediction for quantifying, as their measurement is not easy. The average annual basin values for different water balance components during both the calibration and the validation periods simulated by the model are reported in Table 6. From these components, actual evapotranspiration (ET)

contributed a larger amount of water loss from the watershed, about 86%. High evapotranspiration rate predicted could be attributed to the type of vegetation cover and high temperature associated with the area. Total water yield (WYLD) is the amount of stream flow leaving the outlet of watershed during the time step. Major portion of the rainfall received by the basin is lost as stream flow. The terrain slope got tremendous impact on lateral flow (Lat_Q).). The lateral flow, computed as a percentage of average annual rainfall. In shallow sloping terrain, its impact is very marginal. Groundwater contribution to stream flow (GW_Q) is the water from the shallow aquifer that returns to the reach during the time step, and it varies widely among streams. Usually, the changes of deep percolation and river flow are proportional to the precipitation and indicate that the importance of rainfall in semiarid regions. The water balance components obtained from the model compared with the results of water balance equation in the region. Results showed a good performance of the model in determination of water balance components. Figure 10 shows the water balance components in annually scale in watershed.

Conclusions

This study presents results of sensitivity analysis, calibration, and validation of the hydrologic SWAT model for small agriculture watershed in Samalqan, Iran. Sensitivity analysis of parameters allows us to determine the cause and effect relations in changes of individual parameter values in simulation results. The parameter sensitivity for discharge was tested with 25 parameters. The parameters that the most effect on results of the model were CN2 (moisture condition II curve number), GWQMN (threshold water level in shallow aquifer for base flow), GW_Delay (delay time for aquifer recharge), GW_REVAP (revap coefficient), and ESCO (soil evaporation compensation coefficient). SWAT model was successfully calibrated for monthly discharge using SUFI2 algorithm. The efficiency of the model has been tested by the coefficient

Table 6 Water balance components calculated with SWAT model

Water balance component	Calibrated period (2004–2012)	Validation period (2012–2014)
Precipitation; Precip (mm)	486.5	468.3
Potential evapotranspiration; PET (mm)	1359.0	1377.8
Actual evapotranspiration; ET (mm)	420.5	429.0
Water yield; WYLD	43.7	46.5
Surface runoff; Sur_Q (mm)	1.2	2.5
Soil water; SW (mm)	61.5	45.5
Lateral flow; Lat_Q (mm)	20.2	14.4
Contribution of groundwater to stream flow; Gw_Q	18.5	15.8
Percolation out of soil (mm)	45.0	26.5

Fig 10 Water balance components in annually scale. (calibration 2004–2012, validation 2012–2014)
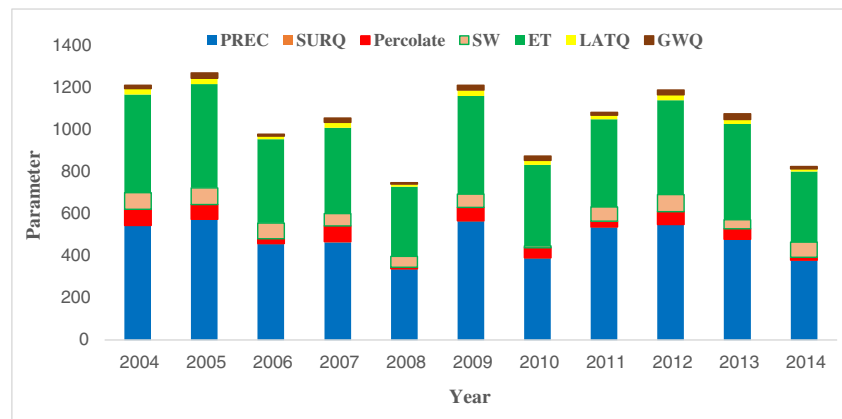
of determination, Nash–Sutcliffe efficiency (NSE), in addition to another two recommended static coefficients: percent bias and RMSE-observation standard deviation ratio. On monthly basis the coefficient of determination and Nash and Sutcliffe efficiency (NSE) were between 0.60–0.80 and 0.80–0.95 respectively, for calibration, and 0.70–0.90 and 0.70–0.80, respectively, for validation periods, which indicate very high predictive ability of the model. Similar approaches concerning the hydrological part of the study comprise, amongst others, Akhavana et al. (2010) evaluated SWAT model for Bahar watershed in Hamedan, Iran, and obtaining R factor, 0.4 to 0.8, P factor 0.2 to 0.6, NSE, 0.3 to 0.8 in monthly scale for the validation period in all rivers. Verma et al. (2010) who used HEC-HMS and received mean values of NSE, R^2, and RSR, for the validation period, 0.74, 0.78, and 0.51, respectively, whilst the corresponding values of the current study are 0.8, 0.85, and 0.55 in outlet of watershed. Golmohammadi et al. (2014) evaluated SWAT for continuous hydrologic simulations obtaining NSE, R^2, and RSR values of 0.73, 0.64, and 0.34, respectively, for monthly time intervals. The corresponding values for the understudy simulations which are performed at daily time intervals amount to 0.85, 0.92, and 0.58, respectively. Water balance components such as surface runoff, lateral flow, base flow, and evapotranspiration have also been simulated. The monthly flow to Samalqan River has been estimated by the model, and the simulated values have shown very close agreement with their measured counterparts. The results in most cases are well-matched with the measured values. But in some months, the values are estimated more than real value and, in some others, less than actual value. These errors can be attributed to errors in measuring the discharge at the stream flow gauges. The accuracy of land use and soil maps, land use, and climate changes in many years have been very effective in simulating, and not considering these changes, causes errors in simulation process. Due to the amount of R^2 and NSE coefficients in the estimation of water balance, it can be concluded that the SWAT model can be used in similar watershed. The performances of the model can be enhanced furthermore by integration of some other climatic data such as solar radiation, humidity, and wind. The calibrated model can be well used to understand and determine the different watershed hydrological processes that help in optimal utilization of river basin. It is recommended to use the calibrated model to assess and handle other watershed components such as the analysis of the impacts of land and climate changes on the water resources as well as the water quality, the sediment, and agricultural chemical yields.

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