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Determination of water balance equation components in irrigated agricultural watersheds using SWAT and MODFLOW models : A case study of Samalqan plain in Iran

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Abstract: Increasing water demands, especially in arid and semi-arid regions, continuously exacerbate groundwater as the only reliable water resources in these regions. Samalqan watershed, Iran, is a groundwater-based irrigation watershed, so that increased aquifer extraction, has caused serious groundwater depletion. So that the catchment consists of surface water, the management of these resources is essential in order to increase the groundwater recharge. Due to the existence of rivers, the low thickness of the alluvial sediments, groundwater level fluctuations and high uncertainty in the calculation of hydrodynamic coefficients in the watershed, the SWAT and MODFLOW models were used to assess the impact of irrigation return flow on groundwater recharge and the hydrological components of the basin. For this purpose, the irrigation operation tool in the SWAT model was utilized to determine the fixed amounts and time of irrigation for each HRU (Hydrological Response Unit) on the specified day. Since the study area has pressing challenges related to water deficit and sparsely gauged, therefore, this investigation looks actual for regional scale analysis. Model evaluation criteria, RMSE and NRMSE for the simulated groundwater level were 1.8 m and 1.1% respectively. Also, the simulation of surface water flow at the basin outlet, provided satisfactory prediction (R^2=0.92, NSE=0.85). Results showed that, the irrigation has affected the surface and groundwater interactions in the watershed, where agriculture heavily depends on irrigation. Annually 11.64 Mm^3 water entered to the aquifer by surface recharge (precipitation, irrigation), transmission loss from river and recharge wells 5.8 Mm^3 and ground water boundary flow (annually 20.5 Mm^3). Water output in the watershed included ground water extraction and groundwater return flow (annually 46.4 Mm^3) and ground water boundary flow (annually 0.68 Mm^3). Overally, the groundwater storage has decreased by 9.14 Mm^3 annually in Samalqan aquifer. This method can be applied to simulate the effects of surface water fluxes to groundwater recharge and river-aquifer interaction for areas with stressed aquifers where interaction between surface and groundwater cannot be easily assessed.

Keywords: Groundwater level; SWAT Model; MODFLOW Model; Recharge; Irrigation

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Introduction

Sustainable water management in a catchment requires full knowledge of hydrological conditions and understanding of the interaction between surface and groundwater flows, especially in arid and semi-arid regions (Epting et al. 2018; Mojarrad et al. 2019). As surface water resources are not independent of groundwater, the development of one, will certainly affect the other. Due to the over-exploitation of the aquifers, many regions of the world face critical water resource sustainability issues (Llamas and Custodio, 2002; Gassman et al. 2007). Following the population growth and the industrial revolution, water use across various sector such as agriculture and industry have increased sharply and as a result, the pressure on water resources is mounting. About 94.8% of Iran has an arid and semi-arid climate with low precipitation and high evapotranspiration rate and therefore, faces water scarcity (Khalili et al. 2016; Sattari et al.

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2018). It is estimated that around 98.7% of freshwater is available as groundwater (Rejani et al. 2008). Given that, our study area consists of both arid and semi-arid regions, the groundwater is the most important water source. The risks are more noticeable in the aquifer with consequences such as declining groundwater levels, saltwater intrusion into the aquifer, land subsidence and wetland destruction. Therefore, it is crucial to study the surface water-groundwater interaction in this area. In order to manage groundwater, a lot of information is needed about the characteristics of the aquifer and the groundwater flow system, which is difficult to obtain and is usually associated with high cost and uncertainty. In this regard, the mathematical models, have made it possible to study low-cost and effective groundwater complex systems. The use of models can enhance understanding the aquifer conditions and resources availability and simulate long-term behavior of aquifers under different management scenarios.

MODFLOW model has been successfully developed and published in a large number of groundwater quantitative and qualitative studies because of its simple methods, modular program structure, and separate packages to resolve special hydrogeological problems (Xue et al. 2018; Chatterjee et al. 2018; Chakraborty et al. 2020). Although ground water and surface water are usually evaluated as separate water masses, they are connected by the ground-water/surface-water transition zone in a hydrologic continuum.

Cho et al. (2009) used a three-dimensional flow model to determine the impact of ground development activities on subsurface flow patterns in the Virginia State aquifer. After finishing the model calibration, they used three scenarios with eight approaches and finally proposed solutions that a distributive-surface model can dynamically eliminate spatial and temporal contradictions between superficial and subsurface models completely. Borsi et al. (2013) examined the modeling of unsaturated and runoff zone flows using a new numerical method. LGR (Local Grid Refinement) and VSF (Variable Saturated Flow) methods have been applied as integrated in MODFLOW code that allow a user to solve the three-dimensional Richard's equation only in the specified sections of the zone. Cao et al. (2013) proposed a ground water simulation model for the NCP area in China to assess various scenarios for water resources development in the area. Jalut et al. (2018) investigated the management of groundwater. They used three scenarios of operation times (12, 8 and 6 hr/d) to test the drawdown of water table. Their results showed that the operation time of 6 hr/d was the optimal operation where the drawdown head does not exceed 8 m after the first year and 15 m at 20th year with no dry cells appearance. The review of previous studies indicated that, determination of the exact rate of recharge is very difficult and groundwater models are not accurately considered it and usually, it is applied to the model as a percentage of precipitation (Gassman et al. 2007). While it is affected by various factors such as meteorological, hydrological, and geological conditions of the region (Su et al. 2017; Nan et al. 2018; Karimi et al. 2019). If there is not an appropriate estimation of the recharge and its local and temporal changes, the simulation results are not reliable. The groundwater recharge is derived from precipitation and irrigation, so quantifying the groundwater contribution to stream flow from irrigation is important for the water resources management.

One of the models that is widely used today to estimate the groundwater recharge through surface water resources (precipitation, irrigation), is the SWAT model (Arnold et al. 2012). In this model, the impact of effective factors on water infiltration into the aquifer is considered and the actual value for recharge is estimated. Uncontrolled abstraction of groundwater resources for agricultural uses along with drought periods has reduced the groundwater storage in the Samalqan plain. Due to unauthorized wells in the aquifer and uncontrolled abstraction, the groundwater level has declined over the past 10 years. So, the main purposes of this research are to simulate the groundwater recharge from precipitation and irrigated cropland, river-aquifer interaction and water balance components in the Samalqan plain using SWAT and MODFLOW models. This research is one of the first studies conducted in this plain with SWAT and MODFLOW models. So, it can provide useful information about the aquifer, surface and groundwater balance estimation. The presented model can be applied to predict the future situation of the aquifer, water resources management and optimum utilization of available agriculture water.

1 Study area

The study area is the Samalqan watershed, which is located between 37°21′ to 37°39′ N and 56°25′ to 57°06′ E with semi-arid to arid climate in Atrak basin, North Khorasan Province, Iran (Fig. 1). The total area is 1 148 km^2 and consists of 927 km^2 mountainous terrain and about 221 km^2 plain. The maximum elevation is located in Korkhod mountains and the minimum elevation is at the outlet of the watershed (Darband). The average annual precipitation is 465 mm, but varies considerably from one year to another. The mean annual temperature is about 11℃ and the annual potential evapotranspiration is 1 132 mm. The Samalqan River is the main stream of the plain. The average daily discharge at Darband-Samalqan station was 0.68 m^3/s for the period of 2004-2014. The area of the Samalqan aquifer is about 158 km^2. According to Iran Water Resources Management Company (IWRMC), There are 205 wells, 25 springs and 7 qanats (systems for transporting water from an aquifer to the surface, constructed in Iran) in the aquifer, that the extraction of these sources was about 39.6 Mm^3 (Iran Water Resources Management Company). Geological and geoelectric studies show that the Samalqan aquifer is single-layer, unconfined and the particle size varies greatly in different parts of the plain. In terms of the geological structure, the study area consists of Young Alluvium and Limestone with layers of Marl and Shale, as well as Sandstone and Conglomerates. In the center of the plain, the protrusion with the lithology of Shale, has changed the topography of the bedrock (Fig. 2). Also, the geological characteristics and soil units in the study are shown in Table 1.

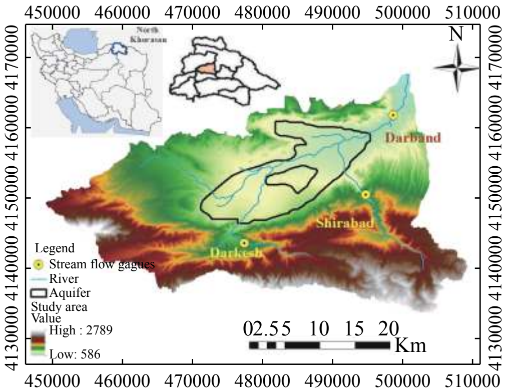

Fig. 1 Location of the study area

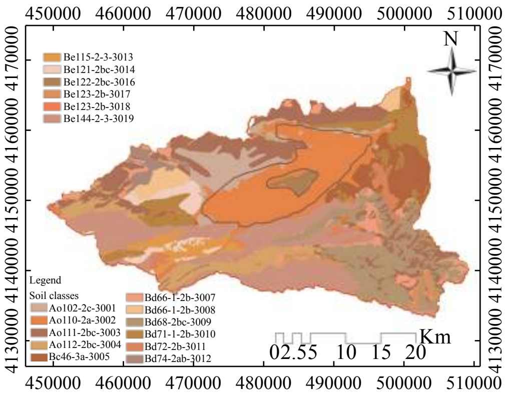

Fig. 2 Geological characteristic and soil units in Samalqan watershed

2 Materials and methods

2.1 Watershed management model (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 was 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). The main advantage of SWAT, is the capability to run simulations for large watersheds without extensive monitoring data and the capacity to predict changes in hydrological parameters under different management practices and physical environmental factors (Gassman et al. 2007; Daloğlu et al. 2014). The land phase of the hydrologic cycle is modeled in SWAT based on the water balance equation (Gassman et al. 2007):

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

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} is the amount of return flow on day i (mm).

SWAT simulates runoff from surface flow, subsurface flow and baseflow, separately. Thus, the SWAT model is chosen to simulate the effect of irrigation return flow on all components of runoff, which enable us to decompose the effect of groundwater-fed irrigation on streamflow and aquifer.

2.2 Surface water flow modeling

In order to simulate the hydrological processes in a watershed, SWAT divides the watershed into sub-basins based on drainage areas of the tributaries. The sub-basins are further divided into smaller spatial modeling units known as HRUs (Hydrological Response Units) to describe spatial hetero-

Table 1 General geological characteristics and 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	3 001
Moderate	Moderate	Conglomerate with poor consolidation	Forest	Moderate	3 002
Low	Low	Thick layer limestone, chert limestone, clayey limestone and marl	Forest	Moderate	3 003
Low	Low	Shale	Orchard-agriculture	Moderate	3 004
Low	Low	Thick layer limestone, chert limestone, clayey limestone and marl	Bare Ground Tundra	Moderate	3 005
high	high	Antelopes, young conifers, alluvial plains, young alluvial river	Orchard-agriculture	Moderate	3 007
Low	Low	Red marl and sandstone with layers of conglomerate	Pasture	Moderate	3 008
Moderate	high	Antelopes, old cones, alluvial plains	Orchard-agriculture	Moderate	3 009
Low	Low	Antelopes, old cones, alluvial plains	Orchard-agriculture	Moderate	3 010
Low	Moderate to high	Orbital insoluble limestone	Pasture	Moderate	3 011
Low	Moderate to high	Orbital insoluble limestone	Forest	Moderate	3 012
Low	Moderate to high	Orbital insoluble limestone	Orchard-agriculture	Moderate	3 013
Low	Low	Clay limestone, marl, sandstone and conglomerate, coarse sandstone and conglomerate	Orchard-agriculture	Moderate to strong	3 014
Moderate	Moderate	Conglomerate with poor consolidation	Pasture	Moderate	3 016
high	high	Antelopes, young conifers, alluvial plains, young alluvial river	Pasture	Moderate	3 017
high	high	Antelopes, young conifers, alluvial plains, young alluvial river	Orchard-agriculture	Moderate	3 018
Low	Moderate to high	Orbital insoluble limestone	Forest	Moderate	3 019

geneity in terms of land use, soil types and slope within a watershed. For simulation, SWAT needs digital elevation model (DEM), land use and land cover map, soil, climate and irrigation management data. The spatial information about the soil and land cover types in the study area prepared by the Department of Natural Resources of North Khorasan Province, has been verified using remote sensing data and Landsat satellite series images. Finally, eight major classes were identified that shown in Fig. 3. According to this figure, the categories are pasture (36.18%), forest (28%), dry land and crop land (24%), agriculture and orchard (10.20%), Bare Ground Tundra (0.82%) and the urbanized areas represent just 0.8% of the watershed. Then the irrigation depths applied to agricultural land use hydrologic response units, according to extraction volume of surface and groundwater resources and the special areas of the HRUs. These data are used as an input for the analysis of hydrological simulation of surface runoff and groundwater recharge. SWAT splits hydrological simulations of a watershed into two major phases: The land phase and the routing phase. Afterward, the

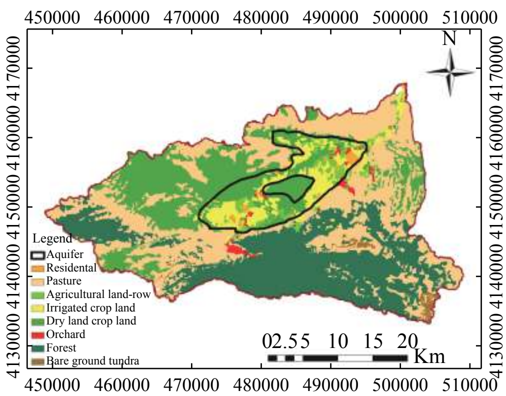

Fig. 3 Land use map of Samalqan watershed

SWAT model was run, calibrated (2004-2012) and validated (2013-2014) based on river discharge, using SUFI2 algorithm in SWAT-CUP (Abbaspour et al. 2007). Spatial and temporal distributions of hydrologic components, i.e. surface runoff, Evapotranspiration, deep percolation, lateral flow and groundwater return flows were simulated for each HRU. Finally, the groundwater recharge rates calculated by the SWAT were considered as an input for the MODFLOW model.

2.3 MODFLOW model

The MODFLOW is the most popular model applied in groundwater studies (Qiu et al. 2015; Moridi et al. 2018; Meredith and Blais, 2019). This model is used to simulate the groundwater flow in aquifers with specified boundary conditions and assuming the necessary values for hydraulic conductivity and other aquifer parameters. The MODFLOW model is a finite difference solution for partial differential equations governing groundwater, which results from the combination of three-dimensional of Darcy and the continuity equations, in the saturated environment (McDonald and Harbaugh, 1988).

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)=S_y\frac{\partial h}{\partial t}\pm W \tag{2}$$

Where: S_y is the specific yield (1/L); h is the height of groundwater surface (L); t is the time (T); K_{xx}, K_{yy} and K_{zz} are the values of hydraulic conductivity in the directions x, y and z, respectively (L/T); W is Volumetric flow flux (1/T), which is negative for discharge and positive for recharge. This equation can be simplified according to the conditions of the aquifer based on heterogeneous or homogeneous, isotropic, or anisotropic, and steady or unsteady.

2.4 Groundwater flow modeling

Understanding groundwater systems usually requires exploratory drilling, pumping operations, and numerous geophysical tests, which are often expensive. Since very few studies have been conducted in the region, groundwater flow modeling can be very useful. The first step of modeling is to describe the conceptual model (Pholkern et al. 2019), which is based on the information of field data and hydrogeological interpretations. Certainly, the accuracy of a conceptual model can be improved by the specific characteristics of the study area, such as groundwater levels, recharge zones and the relationship between groundwater extraction and drainage areas. The data has been received from the Regional Water Company of North Khorasan (RWCNK) to construct the aquifer model based on prepared DEM and bedrocks maps, values of the top and bottom elevations were calculated with inverse-distance interpolation method (Tabios III and Salas 1985), with a 250 m × 250 m cell size. The bedrock depth varies from 0 m to 180 m in the different parts of the plain. Hydrodynamic coefficients, including hydraulic conductivity (K) and specific yield (Sy) are the most important and sensitive parameters in the modeling. The pumping tests are the most practical method of obtaining the hydrodynamic coefficients. Due to the lack of adequate pumping tests in the Samalqan aquifer, these coefficients were evaluated based on specific capacity of wells, theoretical equations, geophysical studies, and these values were used in the model as the initial values and then accurately determined in calibration period.

Furthermore, based on the regional groundwater flow assessed from water-level contour maps for the years 2004-2014, a no-flow hydrological boundary and specified head boundary was assigned to the model.

The initial head was obtained from the piezometers and other measure groundwater level of extraction wells at September 2004. Groundwater withdrawal is equivalent to 39.6 Mm^3/year, based on well data that obtained from Regional Water Company of North Khorasan (RWCNK). There are 16 monitoring wells in the aquifer for measuring the groundwater level and two sewage wells which were applied to the model as two recharge wells due to the lack of a sewage network. The recharge and river packages of the MODFLOW model were used to simulate the groundwater recharge and river flow, respectively. The recharge rates calculated by the SWAT model were imported to MODF-

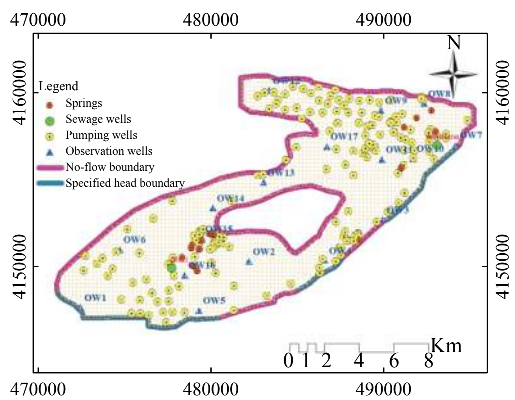

Fig. 4 Location of wells in Samalqan aquifer

LOW recharge package.

The modeling grid (model domain) consists of 54 rows and 90 columns. The total number of grid cells is 4 050, including 1 754 active cells (cells inside the aquifer) and 2 296 inactive (cells outside the aquifer). Fig. 4 shows the boundary condtions and location of wells (pumping, sewage and observation wells) in Samalqan aquifer. The MODFLOW model was calibrated (2004-2012) and validated (2013-2014) by changing a set of parameters values (hydraulic conductivity, specific yield, river bed conductance) based on groundwater level. The process of simulation of the present study is shown in Fig. 5.

2.5 Model performance evaluation criteria

Different criteria are used to evaluate the effectiveness and predictability of the model in calibration and validation processes. These criteria include: Root mean square error (RMSE), normal root mean square error (NRMSE), mean error (ME), and mean absolute error (MAE) presented below. The NRMSE criterion is chosen because the range of groundwater level fluctuations for each observation well varies in the calibration and validation periods, and it seems that the mean root value of the standardized error squares is indicative of the actual error (Thangarajan, 2007).

$$Weighted\ RMSE = \frac{\sum RMSE_i \times a_i}{A} \tag{3}$$

$$Weighted\ drawdown = \frac{\sum \Delta h_i \times a_i}{A} \tag{4}$$

$$Normaloze\ RMSE = \frac{WieghtedRMSE}{Weighteddrawdown} \tag{5}$$

Where: i is the index of each observation well; a and A show the area of each polygon and the total area of the plain, respectively; Δh is the difference between the minimum and maximum fluctuations of the groundwater level. Calculating the above indices is useful in evaluating the merit of the calibration (Thangarajan, 2007).

3 Results and discussion

3.1 Calibration and validation of SWAT model

The observed and simulated mean monthly streamflow in the calibration and validation periods for 3 stream flow gauges in the watershed are shown in Fig. 6. There is a good agreement between simulated and observed streamflow in the watershed according to the model performance statistics in Table 2. Generally, the model simulation is considered as satisfactory if NSE > 0.5 (Moriasi et al. 2007). The results showed that the surface model was considered all the effective factors for estimating groundwater flow such as topography, geology, soil, land use, and climate to determine water infiltration (Arnold et al. 2012).

After calibrating the model, the average annual basin values for different surface water balance components during both the calibration and validation periods which simulated by the model are reported in Table 3. As shown in table 3, the actual evapotranspiration (ET) contributed a larger amount of water loss from the watershed, about 86%. 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

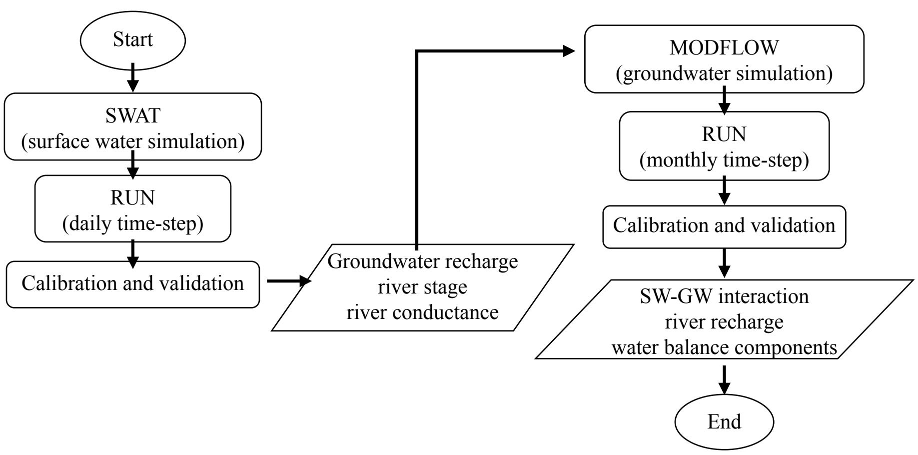

Fig. 5 Flowchart of computation of combined SWAT and MODFLOW models

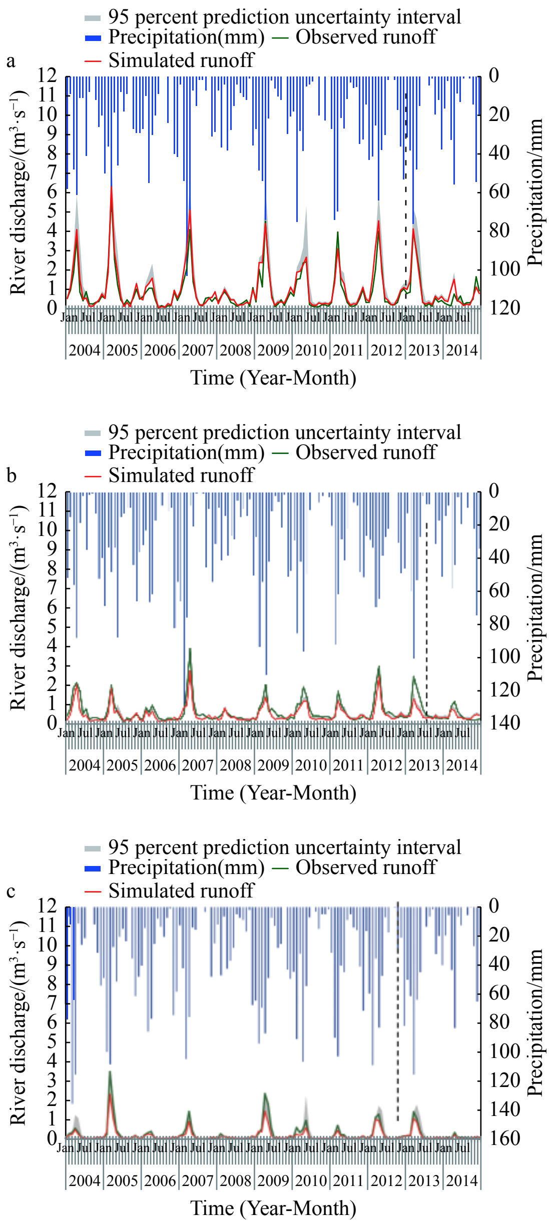

Fig. 6 Plots of observed and simulated mean monthly streamflow during the Calibration (2004-2012) and validation (2013-2014) periods for a) Darband b) Shirababd and c) Darkesh hydrometric stations

average annual rainfall. 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. The groundwater recharge values (GW_Q) for each HRU were extracted and used as an input to MODFLOW recharge package (Fig. 7).

The recharge rates vary from 0 Mm^3 to 2 Mm^3 per year for each hydrologic unit. The highest recharge rates observed in agricultural HRUs. The east and northeast sections of the plain had the minimum recharge amount and in the southwest of the plain, the recharge mostly derived from irrigation return flows. Addition to the irrigation, deep percolation (recharge) and river flow changes are proportional to the precipitation specially in arid and semi-arid regions.

3.2 Calibration and validation of MODFLOW model

In order to carry out calibration operations under transient conditions, suitable minimum and maximum ranges of hydraulic conductivity, specific yield and are calculated. After a trial-and-error process that should be manually changed repeatedly calibration parameters, the automated parameter estimation (PEST), was used and the optimal values of hydraulic conductivity (K) and specified yield (Sy) were obtained. Hydraulic conductivity is the ability of the aquifer to transmit water under the effect of a hydraulic gradient (Lobo-Ferreira et al. 2005) and specific yield is defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table .

Fig. 8 shows the distribution of hydraulic conductivity and specific yield in the aquifer after transient calibration. According to this figure the maximum hydraulic conductivity values were in the northeastern and southwestern regions, while in the middle part of the aquifer the hydraulic conductivity was reduced, which proportional to the grain size of the aquifer particles and varied from 0.10 m/d to 15 m/d. Changes in specific yield had a similar process to hydraulic conductivity and values of this parameter were in the range of 0.05 m/m to 0.20 m/m. The results of geoelectric studies also indicated that fine-grained soil, marine sediments,

Table 2 Model evaluation statistics, calibration - validation periods

Station Name	Coefficients											
	Calibrated period (2004-2012)						Validation Period (2013-2014)					
	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

Table 3 Average annual surface water balance components calculated by the SWAT model

Surface water balance component(mm)	Calibrated period(2004-2012)	Validation Period(2013-2014)
Precipitation; Precip	486.5	468.3
Potential evapotranspiration; PET	1 359.0	1 377.8
Actual evapotranspiration; ET	420.5	429.0
Water yield; WYLD	43.7	46.5
Surface runoff; Sur_Q	1.2	2.5
Soil water; SW	61.5	45.5
Lateral flow; Lat_Q	20.2	14.4
Contribution of groundwater to stream flow; Gw_Q	18.5	15.8
Percolation out of soil	45.0	26.5

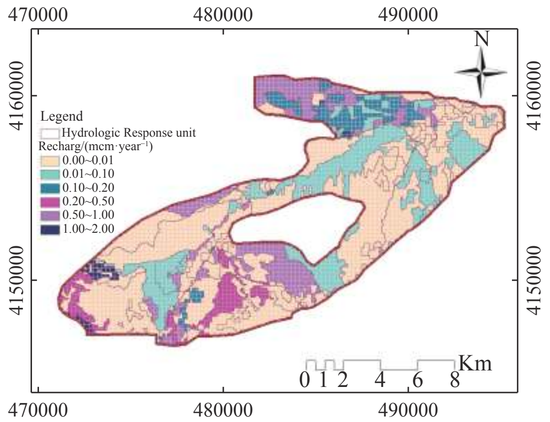

Fig. 7 Mean annual recharge estimated by SWAT

and Neogene conglomerate formed the bedrock of the Samalqan aquifer. It was concluded that the values of these parameters had a decisive role in the results of the model.

The values of RMSE (1.8 m) and NRMSE (1.1%) for 16 observation wells in the aquifer were calculated. According to the results, there is a good agreement between the observational and computational head, so that in most places the model error is low and the model has been able to simulate the natural conditions of the aquifer properly. Fig. 9 shows the groundwater head for the last month of simulation. Groundwater flows from regions of higher hydraulic head to regions of lower hydraulic head. So, the direction of groundwater flow is from southwest to northeast and groundwater recharge occurs in places that the contour lines are closer to each other and the slope is steep. This figure indicates in some areas of the plain, due to the infiltration of agricultural return flow, groundwater level increases and in some areas, groundwater level decreases in the cause of uncontrolled withdrawals. Also, the difference between observed and calculated head values for all piezometers in the aquifer were calculated and for three wells, were shown in Fig. 10. In general, the simulation results of the model were consistently acceptable with the observed values. In model validation, data were used in a time period other than the calibration period and the accuracy of the model was evaluated (Anderson et al. 1992). Changing K and Sy values is not allowed at this stage. Model validation was done for 24 months (2013-2014). The values of RMSE and NRMSE for the present model were about 1.97 and 1.2%, respectively. These coefficients indicate a high correlation between observational and computational values. In fact, the model has been able to simulate the conditions of the aquifer acceptably. As a result, it can be used to predict changes in groundwater level in the future.

3.3 River - aquifer interaction

Rivers are the main sources of groundwater recharge. Many techniques have been used to estimate

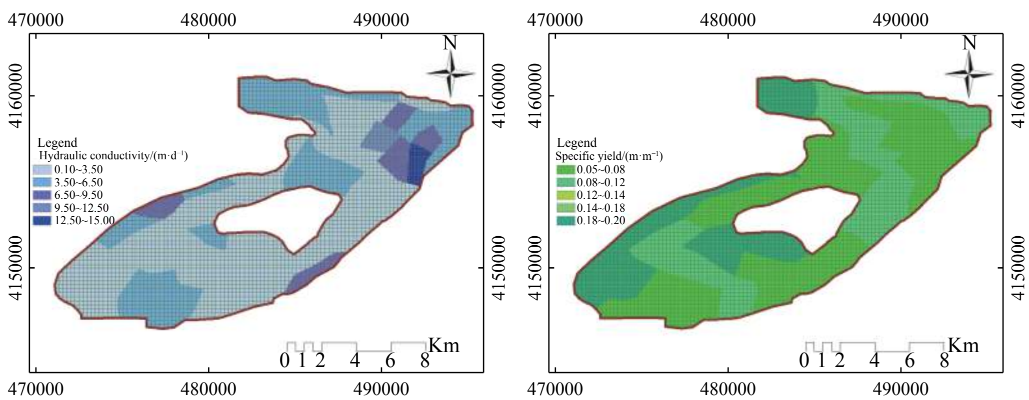

Fig. 8 Distribution of hydraulic conductivity and specific yield in Samalqan aquifer

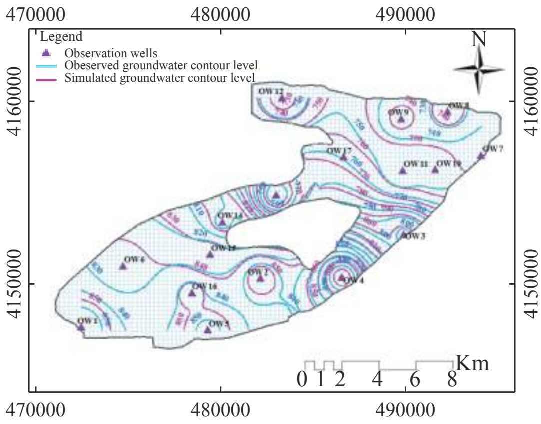

Fig. 9 Groundwater level contour lines for Samalqan aquifer

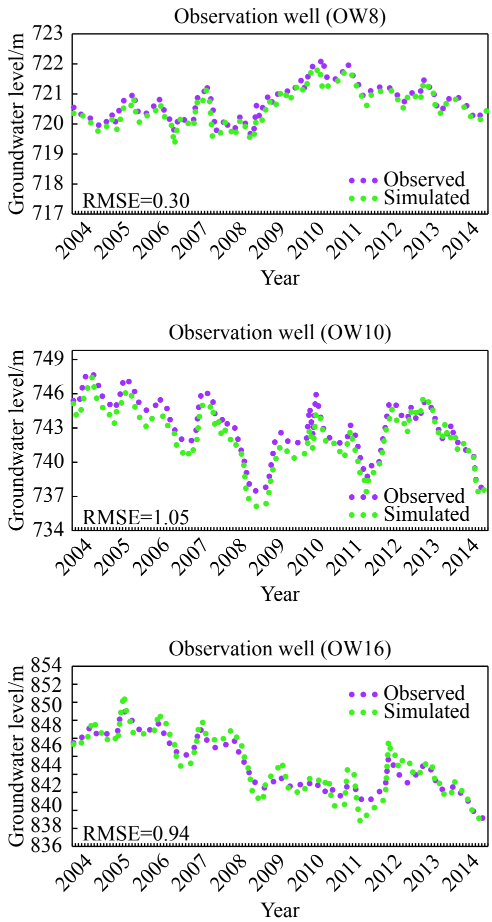

Fig. 10 Plots of observed and computed groundwater level

patterns of groundwater-surfacewater interaction at a variety of spatial and temporal scales. The most important source of surface water in the study area is the Samalqan river which has two main reaches, Shirabad and Darakesh. Currently, there are three stream flow stations (Shirabad, Darkesh and Darband) to measure the river flow. The river package was used to accurately examine the interaction between aquifer and river. The river stage and river conductance were imported to the river cells using the results of the SWAT model and the groundwater level was estimated in the simulation period.

As shown in Fig. 11, irrigation has affected the surface and groundwater interactions in the Samalqan river basin, where agriculture heavily depends on irrigation. The streamflow recorded at gauging stations is the result of dynamic interactions between surface water and groundwater systems over different temporal and spatial scales, where return flow plays a critical role in partially compensating the stream depletion caused by groundwater pumping and changing the process of streamflow response to climatic variability through the conjunctive management of surface water and groundwater systems. The streamflow has decreased in Darkesh and shirabad stations because of the extraction of surface water for agricultural uses. The groundwater level of Samalqan plain, like most of the plains in Iran, continues to decline due to prolonged droughts and over-extraction, especially in the agricultural sector.

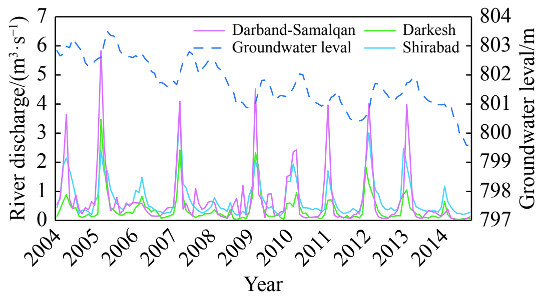

Fig. 11 The relation between surface water and groundwater level in Samalqan watershed

Fig. 12 shows the MODFLOW cells that the river feeds the aquifer. According to the figure, the recharge rate estimated ranging from 0 m/d to 285

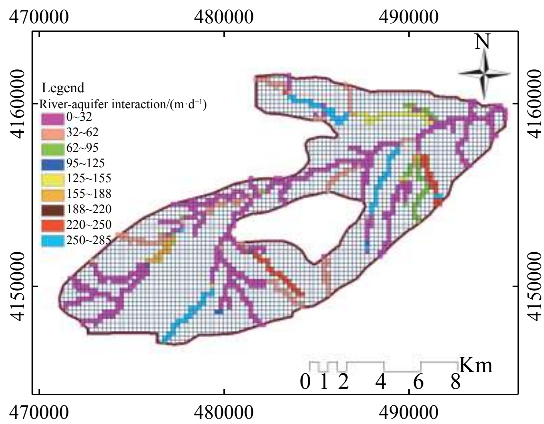

Fig. 12 Groundwater-surface water interaction in MODFLOW cells

m/d, with an average of 4.5 Mm^3. In two reaches entering the plain, due to the low groundwater level and the large alluvial river, the river feeds the aquifer. But at the outlet of the watershed, high groundwater level causes the base flow of the river is supplied by aquifer drainage and irrigation of agricultural land.

3.4 Components of the groundwater balance

Currently, several plains in Iran are forbidden plains and water withdrawal is not allowed. Overcoming water scarcity requires supplying water balance to provide a strategic plan for sustainable development. Therefore, estimation of water balance components is the main part of the research on water resources. Obviously, determining the water balance requires identifying groundwater recharge and discharge zones. The surface water-groundwater modelling of the catchment can provide an appropriate control volume for water balance in a region. The main advantage of this method is that the study area can be divided into smaller area (subbasin or cell) and the flow equation can be solved in these areas to determine the water balance. It should be noted that the accuracy of water balance components is increased using surface and groundwater flow modeling. The groundwater balance components are as follow (Qiu et al. 2015):

$$(Q_{in} + Q_R) + (Q_{out} + Q_E) = \pm\Delta V \quad (6)$$

Where: Q_{in} and Q_{out} are the lateral inflow and outflow; Q_R is the overall recharge (from precipitation, return flow and streambeds); Q_E is the groundwater extraction by pumping and $\pm\Delta V$ is the incremental increase/decrease in groundwater storage.

The annual groundwater components in Samalqan aquifer were calculated from 2004 to 2014. The input components of water balance in the aquifer are infiltration due to precipitation, irrigation return flow, groundwater inflow, drainage from riverbed and infiltration from surface runoff, and the output components are groundwater abstraction and groundwater outflow. In watersheds with intensive irrigation, irrigation return flow is an important human-induced hydrologic process, but it is usually ignored or oversimplified in some existing agricultural watershed models. Irrigation return flow includes both a vertical and a horizontal component. The vertical component infiltrates through the soil profile and recharge aquifer, which will then affect aquifer storage and further baseflow. The horizontal component moves in the soil profile and contributes to rivers as subsurface flow. Moreover, irrigation changes soil moisture, and in turn the soil moisture dynamics affects the timing and quantity of irrigation return flow. Meanwhile the increased soil moisture also helps recharge the aquifer through soil profile percolation. The irrigation return flow depends upon the geological setup of the irrigation command, soil moisture characteristics, meteorological parameters, crop types, method of irrigation and depth to water table. Therefore, assuming constant irrigation return flow can cause many errors in estimating the water balance components and consequently in groundwater management plans. Utilization of both surface and ground water resources requires recognition and behavior analysis of each resource in order to optimize and minimize environmental impact.

According to Table 4, annually 11.64 Mm^3 water entered to the aquifer by surface recharge (precipitation, irrigation), transmission loss from river and recharge wells 5.8 Mm^3 and ground water boundary flow (annually 20.5 Mm^3). Water output in the watershed included ground water extraction and groundwater return flow (annually 46.4 Mm^3) and ground water boundary flow (annually 0.68 Mm^3). Fig. 13 shows fluxes (inflows and outflows) in groundwater system during simulation. As the figure shows, for all the years, the inflow rates are less than outflow and the water balance is

Table 4 Groundwater balance components

Components	In-flow (Mm^3/a)	Out-flow (Mm^3/a)
Inflow boundaries	20.5	
Infiltration of river bed and sewage well	5.8	
Infiltration of Surface water(Precipitation, irrigation return flow)	11.64	
Outflow boundaries		0.68
Discharge and extraction (well, spring)		46.4
Total	37.94	47.08
Storage	−9.14	

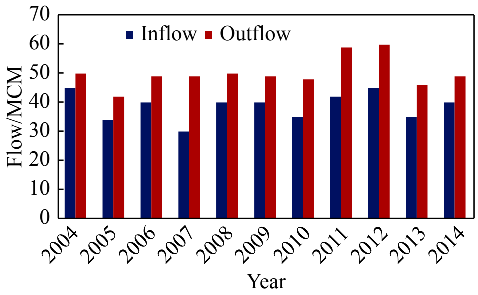

Fig. 13 Comparison of the groundwater balance in simulation period

negative that indicates a notably decline of groundwater about 9.14 Mm^3. Heavy pumping due to recent agricultural activities has led to groundwater decline in the region.

4 Conclusions

According to statistical criteria (NSE= 0.85, R^2= 0.92), the river discharge at the outlet of watershed was simulated accurately. Also, RMSE and NRMSE for 16 observation wells in calibration period were 1.8 m and 1.1%, respectively, which confirmed a good agreement between the observed and simulated groundwater level patterns. The results indicated that, the recharge is one of the most challenging parameters in determining groundwater balance components. The highest recharge rates observed in agricultural land use areas, due to irrigation return flows. The investigation of surface and groundwater interaction showed that, at the outlet of the watershed, high groundwater level causes the base flow of the river is supplied by aquifer drainage and irrigation of agricultural land. Sensitivity analysis showed that hydraulic conductivity (K) and specific yield (Sy) were the most influential parameters on groundwater level in the study area.

Results of water balance in Samalqan watershed showed that annually 37.94 Mm^3 water entered to the aquifer by infiltration from precipitation and irrigation return flow (11.64 Mm^3), and boundary flow (20.5 Mm^3) and transmission losses from river (5.80 Mm^3). Water output in the watershed included ground water extraction, and groundwater return flow annually, 46.40 Mm^3. The groundwater storage has decreased by 9.14 Mm^3/a in Samalqan aquifer.

The results showed that, the factors such as climate change and drought, over abstraction of surface and groundwater resources, authorized and unauthorized wells, and agricultural production with high water demand in the basin have played an important role in reducing the river flow and water table.

In general, the important role of surface water should be considered with respect to groundwater recharge and discharge. surface water management for sustainable groundwater management and recovery from groundwater depletion is necessary. To deal with this situation, the rate of abstraction from the aquifer must be reduced to achieve a balance between recharge and discharge. This study can provide a significant contribution to improve understanding of the groundwater resources in the region, particularly when considering that no prior quantitative analysis had been conducted.

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