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Estimation of groundwater recharge and its relation to land degradation: case study of a semi-arid river basin in Iran

Ammar Rafiei Emam[1] · Martin Kappas[1] · Samira Akhavan[2] ·
Seyed Zeinalabedin Hosseini[3] · Karim C. Abbaspour[4]

Abstract Groundwater extraction is one of the most important criteria of land degradation especially land subsidence in arid and semi-arid areas. Understanding the relationship between water extraction and recharge of groundwater can lead to better watershed management. For the estimation of groundwater recharge in Razan-Ghahavand watershed in Central Iran the Soil and Water Assessment Tools was used. Model calibration was done by using SUFI-2 based on monthly river discharge and annual crop yield, where crop yield was used to better estimate the evapotranspiration term, which consequently increased our knowledge on estimating aquifer recharge. The calibration results were satisfactory: The Nash–Sutcliffe model efficiency ranged from 0.53 to 0.63 for calibration and from 0.42 to 0.72 for validation. The results showed that, although the groundwater level was decreasing about 1 m per year, the groundwater recharge did not change significantly leading to a net withdrawal causing land subsidence over time.

Keywords SWAT · Razan-Ghahavand · SWAT-CUP · Groundwater recharge · Land subsidence · Water balance

✉ Ammar Rafiei Emam
  rafiei99@gmail.com

[1] Department of Cartography, GIS and Remote Sensing, University of Goettingen, Goldschmidt Str. 5, 37077 Goettingen, Germany

[2] Department of Water Engineering, College of Agriculture, Bu-Ali Sina University, 65178-33131 Hamedan, Islamic Republic of Iran

[3] Departments of Natural Resources and Desert Studies, Yazd University, 89195-741 Yazd, Islamic Republic of Iran

[4] Eawag, Swiss Federal Institute of Aquatic Science and Technology, 8600 Dübendorf, Switzerland

Introduction

Groundwater is the main source of water supply in arid and semi-arid regions (Awan and Ismaeel 2014). Exploitation of ground water resource exceeding the recharge, and consequently decrease in the water table is a major cause of land degradation, especially land subsidence and ecological problems such as change of vegetation composition in these regions. An estimation of groundwater recharge can help stakeholders and policy-makers to develop sustainable management of semi-arid regions in Iran. However, the precise prediction of ground water recharge in this area is very complex. Therefore, we simulated the groundwater recharge in a semi-arid region of Iran by SWAT model and we used an innovative technique to calibrate the model.

Desertification today is seen as a broad phenomenon of environmental degradation and its interaction with human populations (Kappas and Propastin 2013). Land degradation is defined the loss of biological or economic productivity and is based on the framework of ecosystems services (Adeel et al. 2005). There are various land degradation phenomena such as soil and wind erosion (Cerdà et al. 2010; Schwilch 2012), vegetation deteriorations (Jafari and Bakhshandehmehr 2013), and groundwater depletion (Motagh et al. 2008; Rafiei Emam et al. 2015a). Cerdà et al. (2013) mentioned that soil erosion as a land degradation phenomenon may have negative impacts on water quality, flooding, river morphology and hence percolation. Soil erosion has been determined by many researchers in different scales (Cerdà and Jurgensen 2011; Bisantino et al. 2013; Mahmoodabadi and Cerdà 2013). Furthermore, the effects of scale on soil erosion and land degradation processes have been discussed by Cerdà et al. (2013). Martínez-Murillo et al. (2013) reviewed the soil erosion in the Western Mediterranean area. Low rate of soil

infiltration in this area resulted in high erosion rate and sediment concentration (Cerdà 1998).

Land degradation could change hydrological conditions. Removing vegetation cover leads to soil surface exposure to the impact of raindrops. The rainfall infiltration into the soil then reduces, soil moisture decreases, runoff increases, flooding occur, water quality deteriorates and groundwater level drops. Generally groundwater is the main source of water supply for irrigation requirements in drylands (Voss et al. 2013; Scanlon et al. 2012), and accelerating of water use can negatively affect the quality and quantity of groundwater resources (Scanlon et al. 2012). The relationship between groundwater and land degradation has been investigated by many previous researchers (Imbrenda et al. 2015; Rafiei Emam et al. 2015a; Zhao et al. 2005). Many recent studies have focused on the decline of groundwater level and water quality (Qi and Luo 2005), the salinity of groundwater and land degradation (Wen et al. 2005), groundwater and vegetation degradation (Ji et al. 2006; Guo et al. 2009), groundwater and change of land cover (Zhang et al. 2005). Fan et al. (2012) analyzed the relationship between groundwater and land degradation (e.g., soil salinization) in Yellow River Delta (YRD). They revealed that raising of groundwater table and an increase of TDS in groundwater are the main causes of soil salinization in last 20 years in YRD. Switzman et al. (2015) analyzed the trends of groundwater level and water budget over time in Wadi El Natrun in Northern Egypt where demand for freshwater is high. They found that groundwater recharge has not changed significantly, whereas long-term groundwater abstraction leads to huge deficit of groundwater in this area. Acharyya (2014) mentioned that rising population as well as impacts of climate change may lead to depletion of groundwater resources and dwindling supply of water in South Asia, China and Africa. Zhang et al. (2014) analyzed the effects of land use/land cover changes on the groundwater fluctuations. The results showed that farmlands sharply expanded within 20 years (1987–2007), which led to rising water consumptions and hence declining groundwater table and land degradation. Chen et al. (2003) mentioned that in northwest China the oasis-ecosystem depends on the groundwater level variability. Any change on water level in this area can significantly affect vegetation growth. Guo et al. (2009) reported that a decrease in groundwater table led to ecological deterioration and desertification in the northwest of China. Motagh et al. (2008) reported that the average of water level in Iranian aquifers have declined about 50 cm annually. They revealed that decrease in the groundwater levels leads to land-surface deformation and land degradation. Rafiei Emam and Zehtabian (2006) revealed that exploitation of groundwater resources in Varamin plain in

the central drainage basin of Iran is one of the main factors of land degradation and salinization in this area.

Although the same hydrological rules apply in both semi-arid and humid areas, physical characteristics are often different (Wisler and Brater 1959). In arid and semi-arid regions the unsaturated zone has a key role on the rate of groundwater recharge. Generally, the separation of rainfall into surface runoff and infiltration is controlled by the unsaturated zone (Raneesh and Thampi 2013). The infiltration of water may move the unsaturated zone through evapotranspiration, and may also percolate through aquifer as a groundwater recharge. To develop good estimate of groundwater recharge, the physical soil properties of unsaturated zone, land use/cover characteristics as well as the climate conditions must be considered.

Groundwater recharge can be simulated by various methods including physical, chemical, isotope or numerical techniques (Scanlon and Alan 2002). A hydrologic model (rainfall/runoff) as a numerical model is used to estimate recharge rates over large areas. Gehrels et al. (2001) revealed that groundwater recharge is an important variable in hydrological models. Singh (1995) reviewed many hydrologic models, which generally estimate groundwater recharge as a residual term in the water-budget equation. Furthermore, various researchers have discussed processes of groundwater recharge estimation based on the water balance concept (Arnold and Allen 1999; Yeh et al. 2007; Barthel et al. 2012). However, the spatial resolution of recharge estimation is different in various watershed models (Scanlon and Alan 2002). Some of them called lumped models provide a single recharge estimation for the entire catchment (Kite 1995), while others are spatially distributed into hydrological response units (HRUs) (Arnold et al. 2000).

In Razan-Ghahavand semi-arid watershed, part of central drainage basin in Iran, intensive agriculture and traditional irrigation methods lead to large amounts of water withdrawal. Groundwater, the main sources of water harvesting in this area, is exploited due to increasing demand and recurrent droughts. Ecological deteriorations such as decreasing of biomass in rangelands, decreasing crop yields, and deterioration of soil are taking place in south of the watershed due to water scarcity. Additionally, mismanagement of groundwater may have led to land subsidence, a dominant land degradation phenomenon in the west of the area, and salinization in central part of the area. Therefore, knowledge about water resource components and in this case groundwater recharge can lead to sustainable management of available resources and also result in best management practice in Razan-Ghahavand area.

The main objective of this research was to estimate the groundwater recharge by means of a hydrologic model. We used an innovative technique to calibrate the hydrologic

model to precisely estimate groundwater recharge. We assessed the relationship between groundwater recharge and groundwater level fluctuation in order to interpret land degradation phenomena such as land subsidence occurrence in the area.

We used the Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998) to achieve this goal. SWAT was selected because it is a continuous time and spatially distributed model, in which components such as weather, crop growth and irrigation, reach routing, water transfer, and agricultural management practices are considered. The advantage of hydrological models is that all water balance components can be estimated over an infinite time series, and distributed hydrological models can account for spatial heterogeneities and provide more detailed information of the hydrological processes in a watershed.

Materials and methods

Study area

The Razan-Ghavand watershed is located in central drainage basin of Iran and has an area of about 3100 km^2 (Fig. 1). The outlet of the watershed is Omarabad in the east. The long-term average daily discharge at this station is 6.7 m^3 s^{-1}. The altitude of the basin ranges from 1577 m in the eastern lowland part of the basin to 2843 m in the hilly part of the basin in northern areas. The climate is semi-arid, and the average annual precipitation, temperature and potential evapotranspiration are about 295 mm, 11 °C, and 1320 mm, respectively. The area is mainly farmland (irrigated and rain fed) and rangeland. Most of the water withdrawal is used for the irrigation of farmlands and for power generation in the Mofatah power plant. In the northern part of the watershed good ecological condition exists with good rangeland and high biomass production, while most of the rangelands degradation and salinization are taking place in the southern part. Land subsidence is prevalent in the western part of the watershed. Geological formation consists of parent rocks such as limestone, shale and conglomerate. The aquifer's area is 1750 km^2 with a thickness about 70–100 m (Amiri 2005). The transmissivity of the watershed ranges from 100 to 750 m^2 day^{-1}, and the average specific yield of the aquifer is 4.5 %. There are 81 piezometric wells well distributed over the area (Fig. 2). Despite the piezometric wells, there are more than 1400 operation wells in the study area, which are extracting groundwater for agriculture, industries and domestic use. The average water level is 30 m in this aquifer, decreasing with an average rate of about 1 m per year.

Fig. 1 Location of the study area in the northwestern part of central drainage basin of Iran (Razan-Ghavand watershed). The location of land subsidence, a dominant land degradation phenomenon in the western area, has been shown in the *map*. The distribution of rain gages and temperature stations and also hydrometric stations has been shown in the *map*
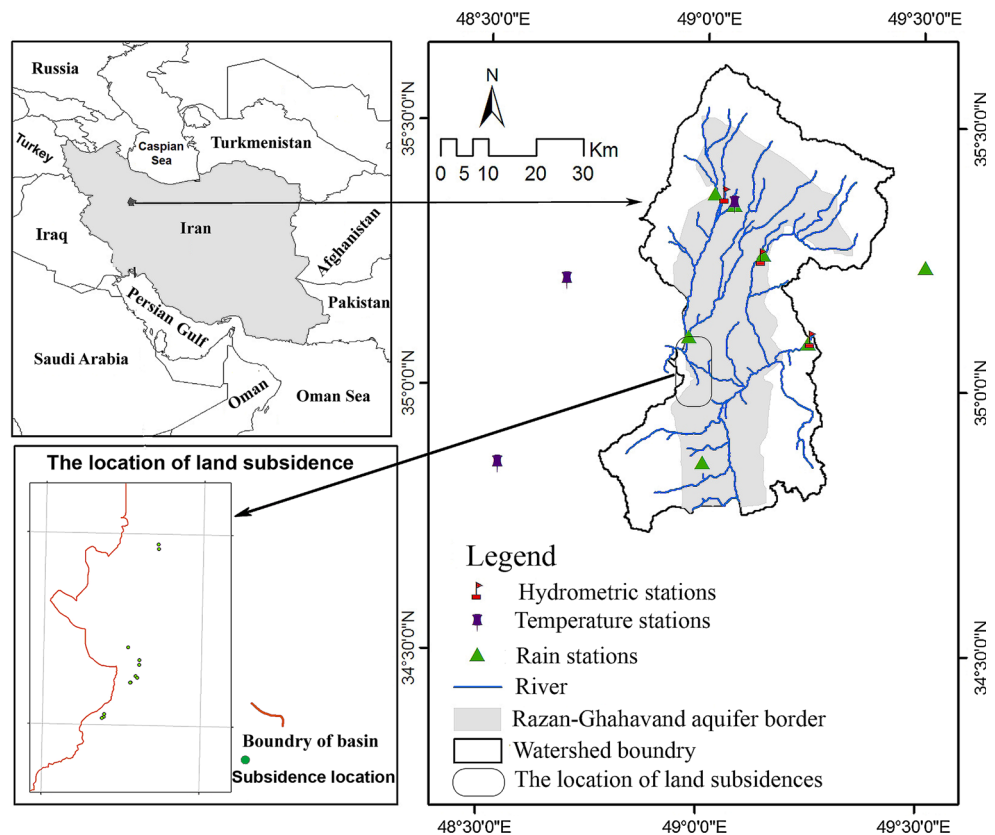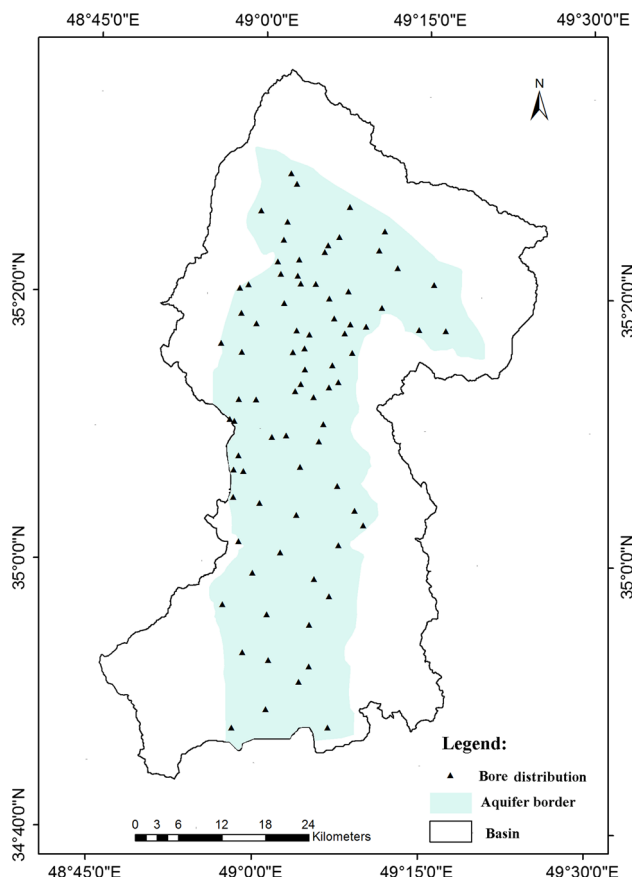
Fig. 2 Location of the piezometric wells in the study area

Groundwater recharge

Estimation of groundwater recharge is complex and depends on groundwater parameters (e.g., hydraulic conductivity), soil parameters, vegetation and land use characteristics, and climate parameters (Arnold et al. 2000). Among various models employed in water balance studies, we used SWAT, Soil and Water Assessment Tools, to estimate groundwater recharge. SWAT simulates the groundwater recharge as a residual of the water balance model. HRUs which are hydrologically homogenous were used as the basis of groundwater recharge calculation. Both shallow (2–20 m) and deep aquifer recharge (>20 m) can be simulated by SWAT at the HRU level. Figure 3 shows the conceptual model of SWAT. The percolation water in the soil profile may percolate as groundwater recharge or loss as lateral flow or evapotranspiration. In shallow aquifer, the water can return through the unsaturated vadose zone by capillary activities to replace the deficit of water for plant evapotranspiration (REVAP), or may also move as a groundwater flow/bypass, the rest move into deep aquifer recharge and become groundwater.

In this study, the groundwater recharge refers to the amount of water leached from the root zone into deep

aquifer. In other words, deep aquifer recharge is a fraction of total groundwater recharge:

$$W_{deep} = \beta_{deep} \cdot W_{rchrg},$$

where W_{deep} is deep aquifer recharge (mm), β_{deep} is aquifer percolation coefficient, and W_{rchrg} is the amount of total groundwater recharge calculated as

$$w_{rchrg,i} = \left(1 - \exp\left[-1/\delta_{gw}\right]\right) \cdot w_{seep} + \exp\left[-1/\delta_{gw}\right] \cdot w_{rchrg,i-1},$$

where δ_{gw} is the delay time (day), w_{seep} is the total amount of water exiting the bottom of soil profile on day i (mm), and $w_{rchrg,i-1}$ is the amount of recharge entering the aquifers on day $i - 1$ (mm). w_{seep} is calculated:

$$W_{seep} = W_{perc,ly=n} + W_{crk,btm},$$

where $W_{perc,ly=n}$ is the amount of water percolation out of the lowest layer (n) in the soil profile on day i (mm), and $W_{crk,btm}$ is the amount of water flow past the lower boundary of soil profile due to bypass flow on day i (mm). Percolation is modeled with a layered storage routing technique combined with a crack flow model (Neitsch et al. 2011). Groundwater recharge was simulated at the HRU level and then compared with groundwater level fluctuations.
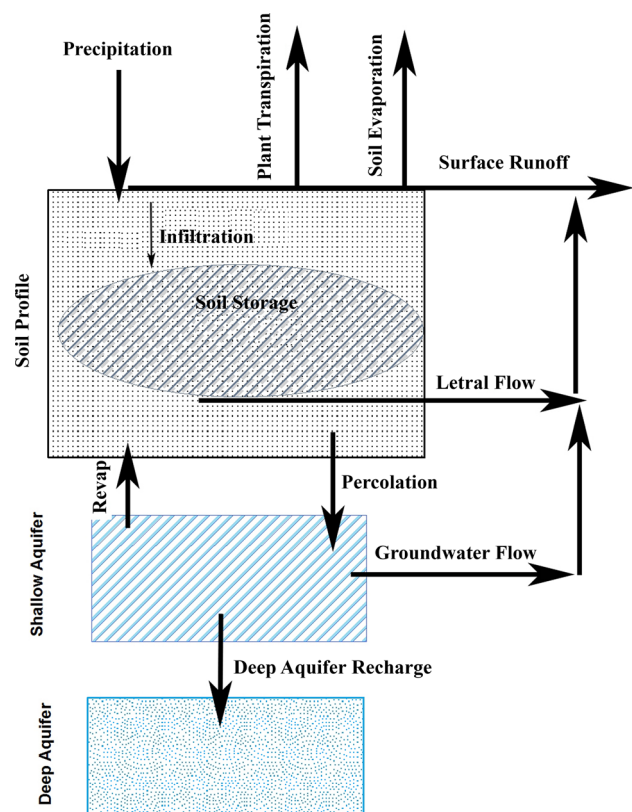
Fig. 3 Conceptual of SWAT model

Model input

For running SWAT a variety of input data (e.g., weather data, soil data) are needed. Weather input data such as daily precipitation, daily minimum and maximum temperature, and daily solar radiations were obtained from the Public Weather Service of the Iranian Meteorological Organization (WSIMO), which had four synoptic, and climatology stations, and 22 rain gauge stations for a period of 31 years from 1977 to 2008. A weather generator model, WXGEN, (Sharpley and Williams 1990) was used to fill the data gap. River discharge data were collected from Iran Water Resources Management Company (IWRMC), and Hamedan Regional Water Co. (HMRW) for 3 outlet stations, Omar Abad, Zehtaran, and Sirabe Khomigan, and one inlet station for the period of 1977–2008. Winter wheat is a dominant crop in the study area and was obtained from 1998 to 2008 in central plain of Razan-Ghavand from Hamedan agricultural organization. Digital elevation model (DEM) and digital stream network map were extracted from topography map of National Cartographic Center of Iran (NCC) with a resolution of 15 m. Land use/land cover map was created from satellite images (Landsat TM) dated in 2009 according to supervised classification (Rafiei Emam et al. 2015b). The landuse/land cover map includes seven classes including irrigated agriculture, rain-fed agriculture, good rangeland, moderate rangeland, weak rangeland, bare lands and urban. A five-layer soil map was generated using soil profile information including 13 types of soil (Soil and Water Research Institute). Physical parameters of each layer such as texture, available water content, field capacity, wilting point, hydraulic conductivity, and bulk density, were estimated by Soil–Plant–Air–Water model, SPAW (Saxton and Willey 2005), and based on silt, sand, and clay content of each layer. The slope map was produced using the DEM in ArcGIS whereat the slope range was divided into three classes: 0–2, 2–5 and >5 %.

Model setup

The first step inside SWAT to set up the model is to create hydrologic response units (HRUs) which are the basis of groundwater recharge calculation in this study. The HRUs are produced by integrating the single sub-basins (by delineation of the watershed according to the DEM and the stream network system), soil, land use, and slope maps. A model is constructed using dominant HRUs (dominant soil and land-use types defining the soil and land use of the sub-basins). A second model is constructed using multiple HRUs (to define HRU, 10 % threshold of land use and soil was selected); in the first step 138 HRUs (or sub-basins) are created and in the second attempt 831 HRUs in the watershed are derived.

Agriculture especially irrigated farmlands have significant influence on groundwater recharge. We simulated the crop growth in order to estimate crop yields in SWAT model. The crop yields further were used in the calibration of the hydrologic model. Winter wheat was chosen as the representative crop in Razan-Ghahavand watershed. For rain-fed and irrigated lands two agricultural schedules are defined according to the information obtained from farmers and the Hamedan Agricultural Organization. Fertilization operations and auto-irrigation, based on water stress thresholds, are used to simulate crop growth due to lack of water use data in irrigation. The Hargreaves method (Hargreaves and Samani 1985) is used to estimate evapotranspiration, which only requires minimum and maximum temperature. Variable storage routing method is selected to route water through the channel network. To adapt SWAT to the conditions of the study area, the curve number (CN) is adjusted based on the slope characteristics. While in SWAT, the default CN is calculated for a slope value of 5 %. We also defined elevation bands for sub-basins with more than 100 m elevation difference and define TLAPS [temperature lapse rate (°C/km)] and PLAPS [precipitation lapse rate (mm H_2O/km)] for these sub-basins. For more detailed information about SWAT see Neitsch et al. (2011).

Model calibration

The model is calibrated and validated at the sub-basin level based on monthly observed river discharges and annually observed crop yield across the watershed. Data from 1997 to 2002 are used for validation and data from 2001 to 2008 are used for calibration including 2 years of warm-up phase.

For calibration of the model and uncertainty analysis, the Sequential Uncertainty Fitting program, SUFI-2 (Abbaspour 2011) is chosen. SUFI-2 is an algorithm for sensitivity, calibration, validation, and uncertainty analysis. SUFI-2 has been used in many studies before for calibration and uncertainty analysis (Abbaspour et al. 2009; Schuol et al. 2008; Faramarzi et al. 2009).

In SUFI-2 algorithm, uncertainties including parameter, conceptual model, and input (e.g., precipitation) are mapped on the parameter ranges. The objective of the procedure was to capture most of the measured data within the 95 % prediction uncertainty (Abbaspour et al. 2007). Model output is expressed as 95 % prediction uncertainty (95PPU), which was calculated at the 2.5 and 97.5 % levels of the cumulative distribution of an output variable obtained through Latin Hypercube sampling. The *P*-factor and *R*-factor were used to quantify the strength of

calibration and uncertainty performance. The *P*-factor is the percentage of measured data bracketed by the 95PPU band, and the *R*-factor is the average width of the 95PPU band divided by the standard deviation of the measured data. Ideally, we would like to bracket most of the measured data within the 95PPU band while having the narrowest band. Nash–Sutcliffe model efficiency (NS) and coefficient of determination (R^2) were used to assess the SWAT model. For crop yield, mean square errors (MSE) was used as the objective function (Akhavan et al. 2010; Faramarzi et al. 2010; Abbaspour et al. 2009).

We identified the most sensitive parameters for each hydrometric station separately by changing specific parameters within their allowable range to obtain the best range. After calibrating the model for hydrology, crop parameters were calibrated including heat unit (HU), bio target (BIO-TARG), harvest index (HI) and auto water stress (AUTO_WSTRS). HU shows growing degree days needed to bring plant to maturity. Biotarget controls biomass produced by the plant every year, and HI is the weight of the harvested portion of the plant biomass divided by the weight of the total aboveground plant biomass. Auto water stress is limiting the need to prescribe exact amounts and timing for irrigation.

Results and discussion

There are many published works on the estimation of groundwater recharge as well as the trend of water level and land degradation in semi-arid regions. Principal differences exist between various methods to estimate groundwater recharge. However, numerical method is widely used to estimate groundwater recharge (Arnold and Allen 1999; Gehrels et al. 2001; Manghi et al. 2009; Xu et al. 2011; Barthel et al. 2012). Most of the researchers focused on the estimation of shallow groundwater recharge, which means water percolates into shallow aquifer. However, we revealed deep aquifer recharge where water percolates into the deep aquifer with depth more than 20 m, while water harvesting from deep aquifer using excavating of deep wells is usual in our study area.

Based on an initial sensitivity analysis, a number of parameters were chosen to calibrate the hydrologic model. These parameters were then regionalized based on their location in the watershed by assigning the sub-basin numbers to the parameter (Table 1). The measure of sensitivity and the significance of sensitive parameters were provided by the *t*-stat and the *p* value, respectively. The initial and final ranges of these parameters are also indicated in Table 1.

Generally, hydrological models are sensitive to various kinds of input variables related to vegetation, land management, soil, weather, aquifer, and channels (Arnold et al. 2000). Finch (1998) revealed that the variables related to soil components (e.g., water capacity) are the most crucial land surface parameters for estimating groundwater recharge. We found the same result in our study. We revealed that the CN and the groundwater delay time (GW-DELAY) are the most crucial parameters, which are related to both soil and vegetation.

Our study showed that the curve number (CN2) is the most sensitive parameter in the mountainous areas; this could be probably due to relatively low rainfall rate in the watershed and steepness of the area. Vaghefi et al. (2014) mentioned that the most sensitive parameter of mountainous Karkheh river basin is CN2. The same result was reported by a number of other studies (Akhavan et al. 2010; Faramarzi et al. 2009; Schmalz et al. 2008). The sensitivity of CN2 parameter is shown in Fig. 4, where an increase in the CN2 values leads to raising runoff and consequently decreasing groundwater recharge and infiltration estimation. The second sensitive parameter in highlands was minimum melt rate for snow in December (SMFMN); this is because snowmelt controls much of the stream flow in the mountainous region. Akhavan et al. (2010) also reported the same result.

The most sensitive parameter in lowlands was groundwater delay time (GW_DELAY) which describes the delay time of water that moves past the lowest depth of the soil profile by percolation or bypass flow before becoming shallow aquifer recharge. This parameter depends on the depth of the water table and the hydraulic properties of the geological formation in the vadose and groundwater zone. Schmalz et al. (2008) revealed the same result for groundwater parameters in low land areas.

The results of model calibration and validation for river discharge were quite satisfactory (Fig. 5). At all stations, the flow dynamics was simulated quite well (R^2 higher than 0.62). The model simulated the time of runoff peak very well, except in some months. For instance, at Omarabad station in April 2004 and 2007 the model simulated the runoff earlier than the actual time, which is probably due to an earlier simulated snow melt (Fig. 5a). Eckhardt and Ulbrich (2003) mentioned that the rising temperature and the earlier beginning of the growing season may have result in this uncertainty. Another possibility could be the paucity of data on water use in the farmlands. This result is comparable to the work of Akhavan et al. (2010) and Rostamian et al. (2008). They also mentioned that SWAT cannot simulate the snow melt precisely; the evidence of this came from the model weakness to simulate peak flow rates in their study, which also has been revealed in some months in our calibration as well. The validation results (Fig. 5b), however, are satisfactory, represented by high NS (66 %) and R^2 (0.69). At Zehtaran station (No. 41), Fig. 5c, d, a *P*-

Table 1 The most sensitive parameters and their initial and final ranges

Parameter	t-value	p-value	Initial range	Final range
r__CN2.mgt_____23,26,27,28,29,32,33,34,37,38,41	−44.67	0.00	−0.5 to 0.5	−0.27 to −0.02
r__CN2.mgt_____1,2,3,4,5,6,12,13,14	−15.06	0.00	−0.5 to 0.5	−0.29 to −0.15
v__SMFMN.bsn	−11.31	0.00	0 to 10	0.0 to 5.5
v__ALPHA_BNK.rte_____1,2,3,4,5,6,12,13,14	−9.39	0.00	0.01 to 1.00	0.02 to 0.17
v__ALPHA_BNK.rte_____23,26,27,28,29,32,33,34,37,38,41	−9.27	0.00	0.01 to 1.00	0.06 to 0.48
r__SOL_AWC().sol_____23,26,27,28,29,32,33,34,37,38,41	7.33	0.00	−0.5 to 0.5	−0.35 to −0.10
v__SMFMX.bsn	−4.93	0.00	0 to 10	1.8 to 5
v__TIMP.bsn	−4.89	0.00	0.01 to 1	0.05 to 0.70
v__GWQMN.gw_____23,26,27,28,29,32,33,34,37,38,41	2.02	0.04	0 to 5000	2028 to 4830
V__GW_DELAY.gw_____1,2,3,4,5,6,12,13,14	2.34	0.02	0 to 500	322 to 407
v__CH_K2.rte_____23,26,27,28,29,32,33,34,37,38,41	2.47	0.01	0 to 150	20 to 65
r__SOL_AWC().sol_____1,2,3,4,5,6,12,13,14	1.97	0.05	−0.5 to 0.5	−0.26 to −0.12
v__GW_REVAP.gw_____23,26,27,28,29,32,33,34,37,38,41	1.78	0.07	0.02 to 2	0.17 to 0.20
V__GW_DELAY.gw_____7–11,15–22,24,25,30,31,35,36,39,40,42–138	1.64	0.10	0 to 500	302 to 401

r parameter value is multiplied by $1+$ given value, v parameter value is replaced by a value from the given range
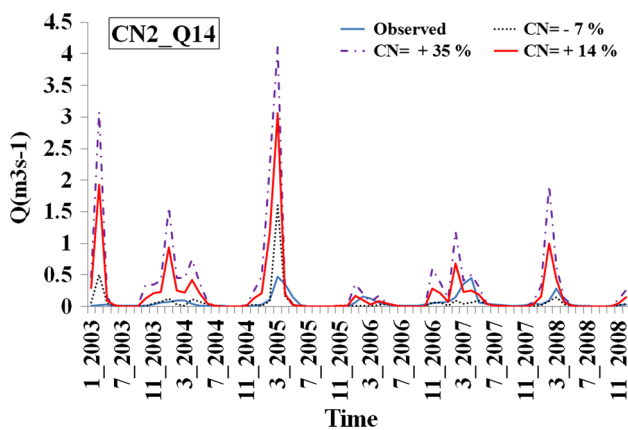
Fig. 4 The sensitivity analysis of CN2 parameter, the *figure* shows the effects of declining (e.g., 7 %) and rising (e.g., 14 and 35 %) of CN2 value on streamflow

factor of more than 0.5 shows that the model simulates the runoff very well at this station. In Sirab-Khomigan (No. 14), Fig. 5e, f, the results of calibration and validation showed a high accuracy of simulation.

After calibration, we compared the statistical results of dominant (with 138 HRU) and multiple or non-dominant (with 831 HRU) models (Fig. 6). The results showed that non-dominant HRU models were more accurate and reliable than the dominant HRU models. We used the more accurate model for further analysis. Many researchers used HRU as a basis of groundwater recharge estimation. Awan et al. (2013) revealed that the HRUs can be used not only to facilitate the identification of the sub-unit's characteristics, but also help to estimate the recharge into the entire basin. Arnold et al. (2000) simulated daily water balance in the HRUs in order to simulate groundwater recharge.

Calibration of model for crop yield

After the calibration of the model by discharge, we calibrated the crop parameters. A good calibration with crop yield would result in a good calibration of evapotranspiration (ET) adding more confidence to simulation of soil moisture and groundwater recharge (Rafiei Emam et al. 2015a). Model uncertainties for irrigated wheat are larger than for rain fed wheat in both calibration and validation results (Fig. 7). For irrigated fields the yield varies from 2430 to 3780 kg ha^{-1}, and for rain-fed fields the yield varies from 890 kg^{-1} ha to 1362 kg ha^{-1}. For irrigated and rain-fed yield, the p-factor was quite satisfactory and varies from 0.67 to 0.92. The r-factor was quite small for rain fed rather than irrigated yield which indicates low uncertainties of prediction. Vaghefi et al. (2014) mentioned that a p-factor larger than 0.73 for irrigated yield is satisfactory in a semi-arid river basin of Karkheh in Iran.

The RMSE for rain fed yield was just 70 kg ha^{-1} and 250 kg ha^{-1} in calibration and validation period, respectively, what documented high accuracy of rain fed calibration. In irrigated lands the RMSE varies from 190 kg ha^{-1} to 691 kg ha^{-1} both for validation and calibration. Akhavan et al. (2010) mentioned the high range of RMSE (80–4220 kg ha^{-1}) for calibration and validation of crop yield (e.g., wheat and potato) in Hamedan area, Iran. They revealed that the large RMSE could be owing to the lack of data concerning to management practices (e.g., tillage operation, irrigation operation, planting date), which can be accounted also in our study area. The same limitation is also reported by Faramarzi et al. (2010). Overall, the calibration and validation of crop yield in our study was satisfactory due

Fig. 5 Result of calibration and validation in **a**, **b** Omarabad station (No. 71); **c**, **d** Sirab khomigan station (No. 41) and **e**, **f** Zehtaran station (No. 14)
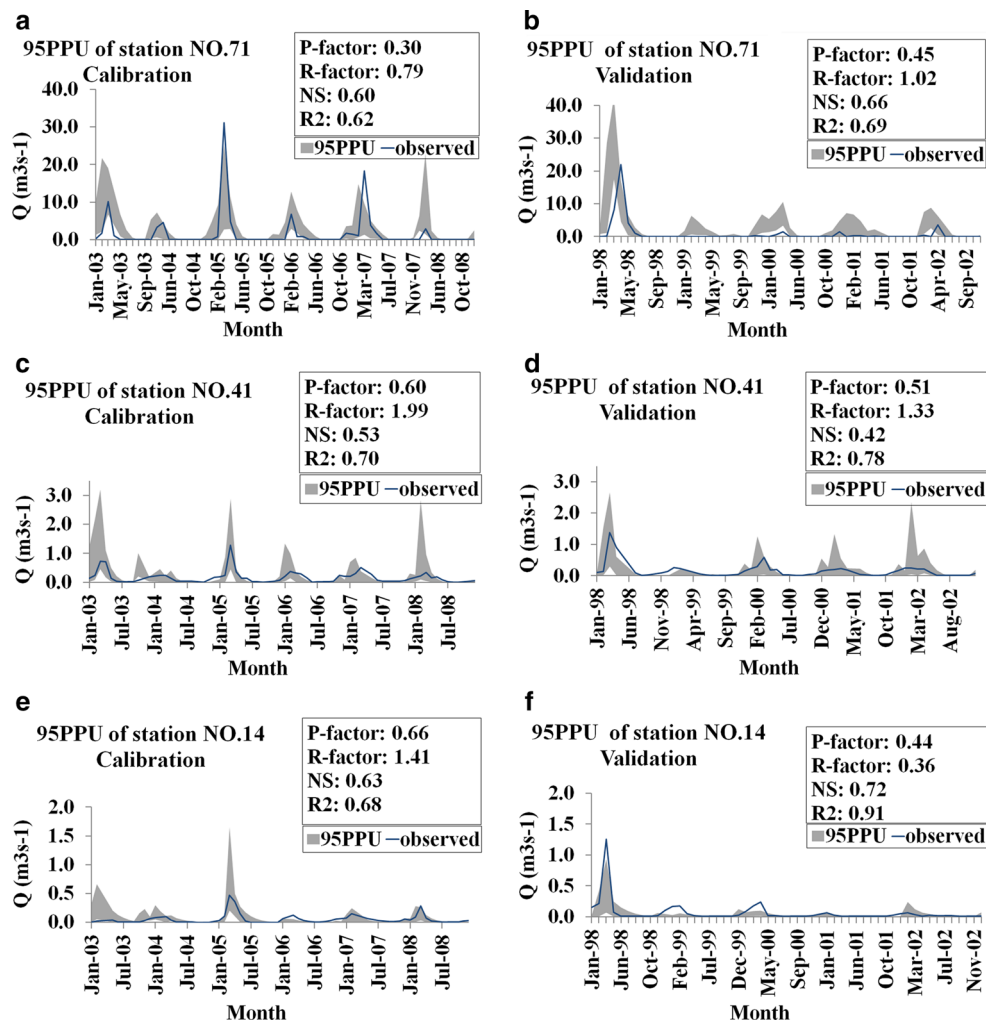
to low RMSE and pretty high value of *p*-factor both in calibration and validation period.

Groundwater recharge, water level and land subsidence

The process of river discharge and crop simulation in the study area did not only lead to model parameters being defined, but also allowed the delineation of the recharge rate. In other words, with calibration of river discharge and crop yield, the recharge rate can be estimated with high confidence. Sun and Cornish (2005) reported the same result. Githui et al. (2012) used river discharge and evapotranspiration data in order to calibrate the SWAT model for groundwater recharge estimation. Immerzeel and Droogers (2008) also mentioned that ET is useful to better simulate the water balance components such as groundwater recharge. Estimated groundwater recharge was analyzed for an 11-year period from 1998 to 2008. The estimated annual average recharge for this period (1998–2008) was 4.8 mm/year. Figure 8 shows that

recharge has been dominated by the period surrounding 2003. A rather meaningful relationship is seen between groundwater recharge, simulated by SWAT, and observed groundwater level (Fig. 8). A sharp decline in water level from 1998 to 2002 is accompanied by a decreasing groundwater recharge. As groundwater recharge increased from 2001 to 2003, groundwater level remained rather constant until 2005, which started to decrease again as groundwater recharge decreased.

Figure 9 shows the groundwater and precipitation distribution in the watershed. The result of water balance showed that precipitation in the north of the watershed is higher than in the southern part. In the south, the average precipitation is below 265 mm per year. Ghahavand desert is located in this part. These areas are degraded because of huge groundwater extraction for irrigation and also for using in power production at Mofatah power plant in previous years and now most of the area is salinized with large occurrences of land subsidence. In the north of the watershed, precipitation is higher than 300 mm per year with good rangeland and ecological condition. Groundwater
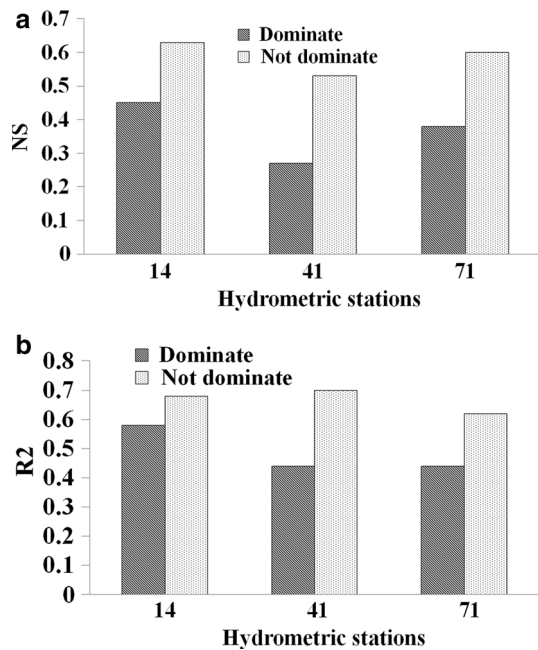
Fig. 6 **a**, **b** Statistical results of dominant and non-dominant HRU in SWAT model
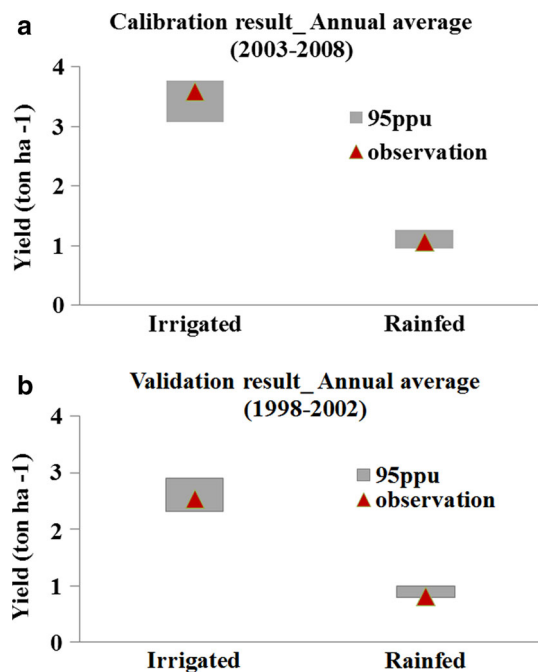
Fig. 7 **a**, **b** Calibration and validation results of annual average (2003–2008 for calibration and 1998–2002 for validation) crop yield for rain-fed and irrigated wheat in study region. The *red sign* is observation, and the *gray band* expresses the 95 % prediction uncertainty (95PPU)

recharge is high in the north, especially in northeast portion of basin. Apart from the amount of precipitation, land use/land cover (LULC) and soil type had significant effect

on groundwater recharge. In the northeast of the basin, there is coarse soil texture, which leads to high groundwater recharge, whereas in the central and south part of the area, there is finer soil texture which resulted in low groundwater recharge. It is important to note that improper agricultural practices can decrease the soil quality and change the hydrological behaviors (e.g., increasing runoff, decreasing recharge) in the agricultural watershed especially in the semi-arid areas (García-Orenes et al. 2012; González-Peñaloza et al. 2012). Awan and Ismaeel (2014) mentioned that HRUs that have built-up settlements have no groundwater recharge. They revealed that sandy loam textures have the largest amount of groundwater recharge in compare to other types of texture in the study area in Punjab province, Pakistan.

The estimation of temporal precipitation showed an increase in average annual precipitation in 2002 and 2003 (Fig. 10) and resulted in raising groundwater recharge in 2003. More than 16 % of precipitation (62 mm) in 2002 occurred in December, which significantly affected the hydrological process in 2003.

Borehole data from 1998 to 2008 were investigated comprehensively using 81 borehole sites. The water level in the north of the aquifer is more or less constant while in the west of the aquifer water levels varied in different places. The depth of groundwater level is from 0.5 m in the north to 140 m in the west of the aquifer. Among all, six piezometric wells were selected around the aquifer to assess the water level fluctuations (Fig. 11). The groundwater level assessment showed that a minimum groundwater decrease was observed in wells No. 1, 2 and 3 in north and eastern part of the study area, and the maximum groundwater level decrease was observed in wells No. 5 and 6 (in the West and South West of the region). Groundwater levels in the west and south west of the aquifer have experienced a steady decline as a result of increasing groundwater extraction for agricultural
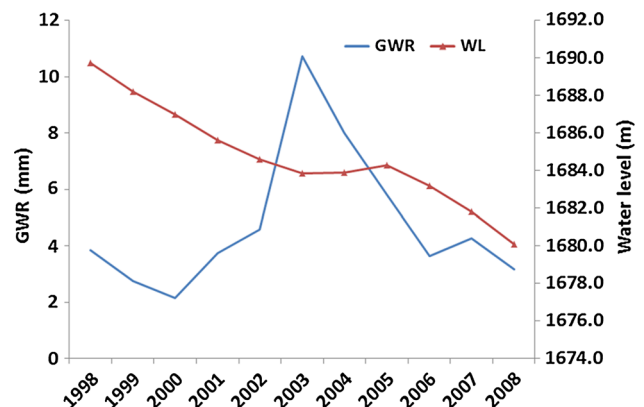

Fig. 8 The relationship between mean annual groundwater recharge and groundwater level from 1998 to 2008

Fig. 9 Average yearly groundwater recharge and precipitation distributions at the sub-basin scale
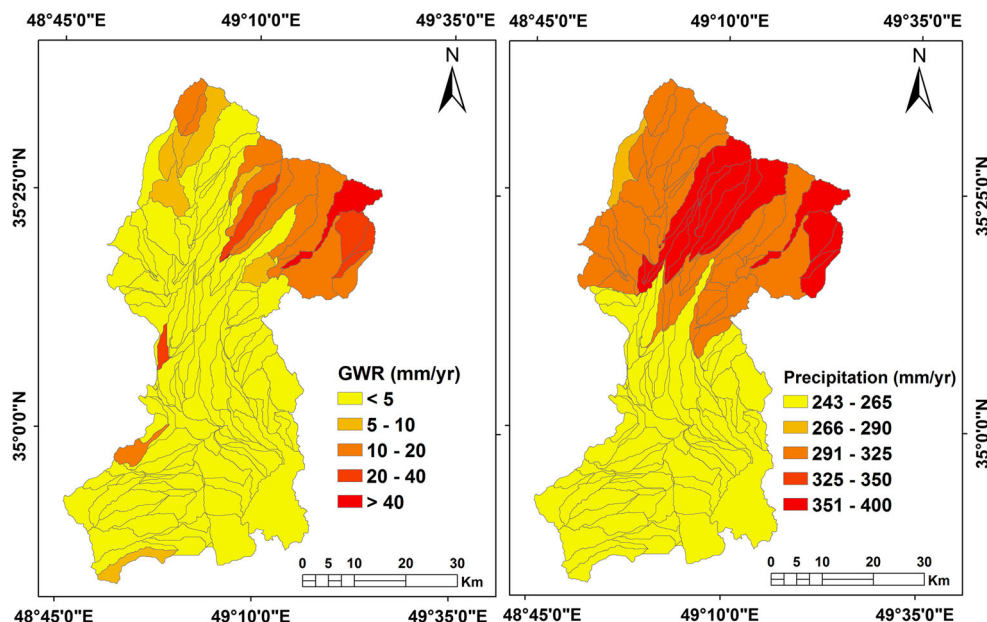

Fig. 10 Mean annual precipitation in Razan-Ghahavand study area, showing drought cycles during 1998 and 2008. An increase precipitation in 2002 and 2003 may have significantly increased on groundwater recharge in 2003
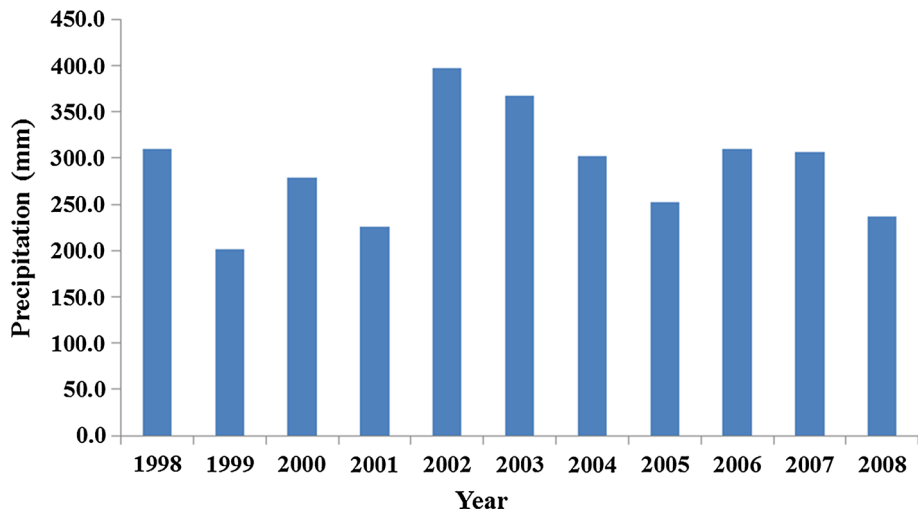

irrigation purposes and also of water use of the Mofatah power plant. In the north and east of the region there is no significantly declining of the groundwater level.

Most of the land subsidence occurred in the west of the watershed which has been shown in Fig. 1. This area is under intensive agriculture use. The comparability of groundwater recharges and point measurements of groundwater level in the sub-basin assigning land subsidence in the west of the watershed is shown in Fig. 12. The figure shows that groundwater level decreased by about 40 m during this time, but the recharge did not change significantly. The trend of groundwater level was not the same as the groundwater recharge. Water extraction exceeded that of recharge which caused the groundwater level to decrease. Timothy (2006) mentioned that more
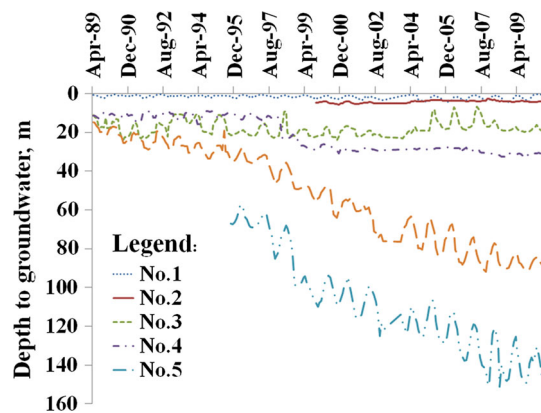
Fig. 11 Depth to groundwater level at different locations in the study area. Bore Nos. *1*, *2*, and *3* are located in North of area. Bore No. *4* in East, and bores No. *5* and *6* are located in West of area

Fig. 12 The trends of groundwater recharge and groundwater level in west of the watershed, where land subsidences have occurred
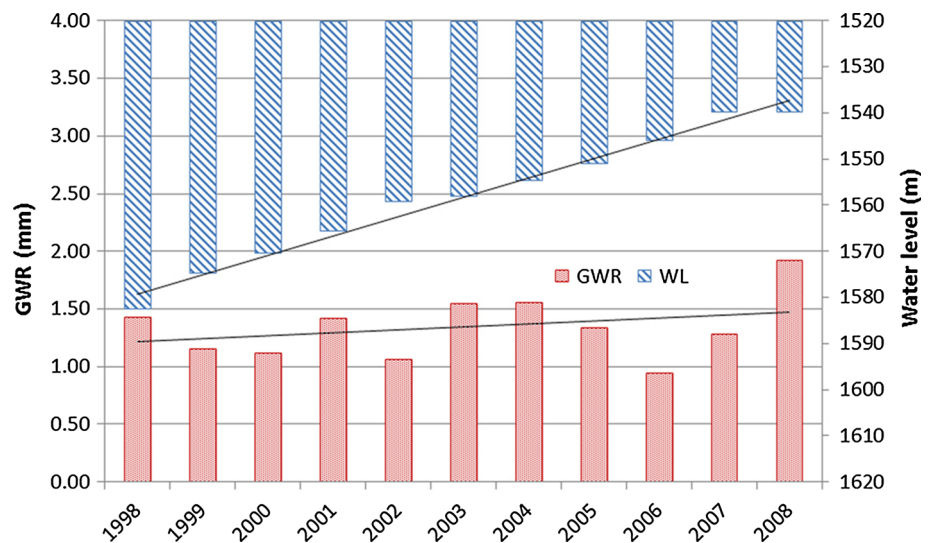
than 80 % of serious land subsidence problems are associated with huge withdrawal of groundwater, making it a growing problem throughout the world. On the other hand, poorly managed irrigation systems and high removal of groundwater for irrigation purposes lead to increasing critical groundwater levels, enhancing secondary salinity (UNDP 2007). We also generally projected the same result in our study area (e.g., in central and east of the basin salinization appeared in farmlands). Land degradations turn out to be costly in the agricultural lands. Awan et al. (2013) cited that land salinization and degradation of farmlands in Uzbekistan leaded to costs of US $31 million annually.

Summary and conclusions

The concept of HRU that was used in this research, made it possible to recognize the influence of variables on groundwater recharge. In this study, we demonstrated that the more detailed HRU use in the model (multiple HRU model approach) had the better performance of the model in a semi-arid region of Razan-Ghahavand. The definition of model parameters played a key role in precise estimation of groundwater recharge by the SWAT water balance model. The model was calibrated both by surface runoff and crop yield with uncertainty analysis. SWAT has been extensively tested for a variety of climates; however, little is known about its performance in semi-arid regions where river discharge is too low normally with high pick flow in flood events, or even there are just seasonal streams which make the model too complex for precise calibration. Lack of data on the amount of water used in irrigated lands was another limitation of this research.

Temporal and spatial estimation of groundwater recharge can provide detailed information for decision-makers and stakeholders to regulate groundwater recharge for sustainable development. The annual average of groundwater recharge was verified by independently observed borehole data in the study area. Awan et al. (2013) presented the same method. In general, temporal assessment showed that groundwater recharge did not change significantly during the time step from 1998 to 2008, except in 2003 due to highest precipitation, while the water table declined about 1 m per year. In particular, the water level was decreased about 3.6 m in year in the west of the watershed with no significantly change in recharge. Overexploitation of groundwater was the main reason of the declining water level.

Groundwater is the main source of water in the study area and more than 90 % of groundwater was used for agriculture while the rest went for industry and drinking. As the amount of water withdrawal is more than the water recharge and the bedrock in the west of the basin is limestone, overexploitation of water lead to joints and fracture systems in the bedrock, which is one of the main causes of land subsidence in this area.

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