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REPORT

Determining the groundwater potential recharge zone and karst springs catchment area: Saldoran region, western Iran

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Abstract Assessing the groundwater recharge potential zone and differentiation of the spring catchment area are extremely important to effective management of groundwater systems and protection of water quality. The study area is located in the Saldoran karstic region, western Iran. It is characterized by a high rate of precipitation and recharge via highly permeable fractured karstic formations. Pire-Ghar, Sarabe-Babaheydar and Baghe-rostam are three major karstic springs which drain the Saldoran anticline. The mean discharge rate and electrical conductivity values for these springs were 3, 1.9 and 0.98 m^3/s, and 475, 438 and 347 µS/cm, respectively. Geology, hydrogeology and geographical information system (GIS) methods were used to define the catchment areas of the major karstic springs and to map recharge zones in the Saldoran anticline. Seven major influencing factors on groundwater recharge rates (lithology, slope value and aspect, drainage, precipitation, fracture density and karstic domains) were integrated using GIS. Geology maps and field verification were used to determine the weights of factors. The final map was produced to reveal major zones of recharge potential. More than 80 % of the study area is terrain that has a recharge rate of 55–70 % (average 63 %). Evaluating the water budget of Saldoran Mountain showed that the total volume of karst water emerging from the Saldoran karst springs is equal to the total annual recharge on the anticline. Therefore, based on the geological and hydrogeological investigations, the catchment area of the mentioned karst springs includes the whole Saldoran anticline.

Keywords Karst · Geographic information systems · Groundwater recharge/water budget · Iran

Introduction

Karst aquifers have complex characteristics which make them different from other aquifers (Bakalowicz 2005; Freeze and Cherry 1979; Todd and Mays 2005). Karst presents an extremely heterogeneous porosity (Fetter 1999; Ford and Williams 2007). It is necessary to carry out investigations to define the catchment area of karstic aquifers (Bonacci and Andric 2015). Determination of a karst spring catchment is one of the most complex and difficult problems to deal with in the fields of karst hydrology, hydrogeology and geology due to unknown morphology of underground karst features and also the variability in time and space (Raeisi and Karami 1996, 1997; Bonacci et al. 2006). Catchment-area determination is based on geological, topographical, and hydrogeological parameters and meteorological data. Normally, in groundwater exploration, most studies rely on determining the amount of recharge and locating the highest-elevation recharge zones as a first step, thus determining the groundwater catchment area, hydrologic water budget and flow directions (Freeze and Cherry 1979; Shaban 2003). Recently, remote sensing has been increasingly employed to examine the groundwater recharge and to evaluate the spatial–temporal difference in the study region (Foster et al. 2004; Shaban et al. 2006; Yeh et al. 2009). Aerial photographs, geology maps, a land use database, and field verification have been used together to determine the weighting of factors contributing to the groundwater recharge, using geographical information system (GIS) methods and remote sensing (Saraf and Choudhury

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1998; Sener et al. 2005). Many studies have used GIS as a useful tool for integrating the assessment, monitoring and management of groundwater resources and determining the groundwater recharge potential zone (Krishnamurthy et al. 1996; Saraf and Choudhury 1998; Murthy 2000; Bierwirth and Welsh 2000; Leblanc et al. 2003; Shaban et al. 2006; Tweed et al. 2007; Yeh et al. 2009). Important karstic aquifers are located in the west of Iran, which need to be studied from a hydrogeological point of view, thus the study area is located in Saldoran karstic region. It is characterized by a high rate of precipitation, mostly in the form of snowmelt. Unfortunately, no reliable studies have been conducted to estimate the amount of recharge water. The main goals of this study were to estimate the recharge rate of water into the subsurface media, the production of a recharge potential (RP) map, and finally to determine the catchment areas of the different karstic springs in the study area.

Geological and hydrogeological settings

The study was conducted in the Saldoran karstic region in western Iran. It is situated in the Zagros Simple Folded Zone (Talbot and Jarvis 1984), which is one of the major geological terrains of the Iranian plateau (Stocklin and Setudehnia 1977; Alavi 2004). Zagros Simple Folded Zone is characterized by a repetition of long and regular anticlinal and synclinal folds (Miliaresis 2001). Anticlines are well exposed and separated by broad valleys. Fold axes have a northwest to southeast trend. The High Zagros is very close to the main Zagros thrust fault where it is crushed and intensively faulted. The stratigraphic and structural setting of the Zagros sedimentary sequence has been described in detail by James and Wyned (1965), Falcon (1967), Stocklin and Setudehnia (1977), Bordenave (2008) and Alavi (2004). The highest elevation in the study area is 3,621 m above sea level (asl) on the Saldoran Anticline. Many thrust faults have been reported in the study area which comprise outcrops of different formations. These faults exhibit the same trend as the main Zagros thrust fault. Due to the activity of these thrust faults, the southwest of the Saldoran anticline was crushed (Fig. 1). This anticline is mainly composed of limestone and dolomite of Asmari and Sarvak karstic formations. Two cross sections have been constructed across the anticline (Fig. 1). The main outcrop formations, in decreasing order of age, are Mila dolomite and limestone formation (Cambrian), Dalan dolomite formation (Permian), Sarvak limestone formation (Cretaceous), Kashkan Red sandstone and conglomerate formation (Paleocene–Eocene), Asmari limestone formation (Oligocene to early Miocene), Bakhtiari conglomerate formation (late Pliocene–Pleistocene) and recent alluvium. Due to the thrust faults activity, the Hormuz salt formation crops out in the southwest of the Saldoran Anticline. The Hormuz Salt Formation was deposited during Upper Precambrian to Middle Cambrian times. Tectonic activity plays an important role in the development of fractures and fissures in the limestone formations and the subsequent karstification in the area. The precipitation in this area is mainly in the form of snow, which is indicative of a favorable environment for the karstification. The lithology and climatic conditions in this area are associated with different geomorphological karstic features such as caves, voids, dry valleys, polje, sinkholes and springs. In spite of abundant precipitation, there are no permanent rivers in the study area. The recharge rate is high due to the existence of highly permeable fractured karstic formations, creating an important karstic aquifer in the Saldoran anticline. Pire-Ghar, Sarabe-Babaheydar and Baghe-rostam are three major karstic springs which drain the Saldoran anticline. The mean discharge rate and electrical conductivity of these springs were 3, 1.9 and 0.98 m^3/s, and 475, 438 and 347 μS/cm, respectively. A direct relationship between rainfall and discharge rate of the springs was observed. The discharge rate fluctuates at 0.47–8.6 m^3/s in Pire-Ghar, 0.1–3.2 m^3/s in Sarabe-Babaheydar and 0.5–5 m^3/s in Baghe-rostam spring, while the mean annual rainfall and temperature vary: 750–1,000 mm and 2–28 °C, respectively.

Methods of study

The geology, hydrogeology and GIS methods were used to define the catchment areas of the major karstic springs in the Saldoran anticline. The initial map of the catchment areas was determined using Google-Earth software based on direct on-site observations such as the major geological formation, existence of permeable layers and precise analysis of lineation and slope direction. Also, the major karstic facies such as sinkholes, karren, voids, dry valley and faults were investigated on-site. In order to determine the catchment area based on hydrogeological methods, the water balance of the springs was calculated. The catchment area (A) was calculated based on the following formula:

$$A = (Qt)\Big/(PI) \qquad (1)$$

where Q is the annual discharge rate of the spring, P is the annual rainfall value and I is the recharge rate for the catchment area of the spring. Remote sensing and GIS tools were used to generate the recharge potential map and recharge rate. Remote sensing technology such as aerial photos, was used in order to classify the topography, geological features and distribution of the drainage in the study area. The geologic maps and on-site investigation were adopted to quantitatively and qualitatively describe the hydrogeological conditions of the area. Influence of the groundwater recharge factors and their interaction were examined. Thematic maps including lithology, slope value and aspect, drainage, precipitation, fracture

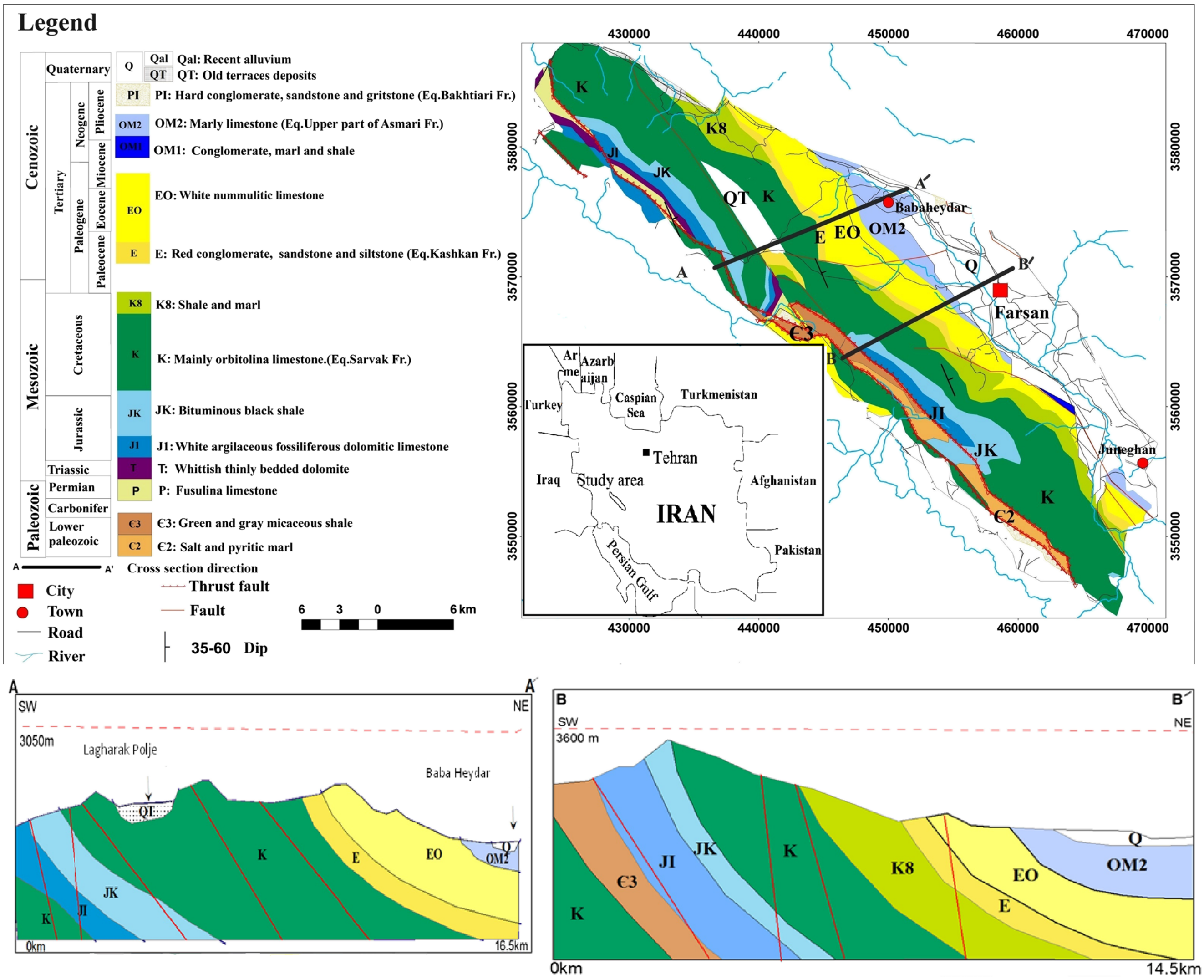


Fig. 1 Geological map and cross sections of the study area

density and karstic domains were generated, as the seven significant factors affecting groundwater recharge potential, using GIS techniques merged with satellite data and other collateral information. Weighting values of each factor were assigned according to the on-site situation. A factor with a higher weight value shows a larger impact on groundwater recharge. Spatial integration and analysis was performed using GIS technology to determine the groundwater recharge potential zone and recharge rate.

Results and discussion

Karst spring catchments represent complex water transport systems in which the heterogeneity of surface and underground karst develop (Bonacci et al. 2006). A karst drainage basin is a mapping unit defined by the total area of surface and subsurface drainage that contributes water to a conduit network and its outlet spring or springs. The catchment areas of the major karstic springs and recharge potential map in the Saldoran anticline are determined based on the geology and hydrogeology methods using GIS tools.

Determining the recharge rates

This study analyzed the hydrologic and geographic attributes of the Saldoran basin, and identified seven major factors influencing groundwater recharge rates, namely lithology, slope value and aspect, drainage, precipitation, fracture density and karstic domains. GIS methods were used to integrate these seven contributing factors. The weights of factors contributing to the groundwater recharge are derived from aerial photos, geology maps and field verification; however, each factor was studied independently, thus seven major categories were plotted to arrive at qualitative recharge rates. Categorizations of the factors influencing recharge potential such as effective domains, and proposed scores in the Saldoran basin are listed in Table 1. The effective weight of each recharge potential factor is proposed in Table 2. Analytical results demonstrate that the factors influencing the groundwater recharge rates of the Saldoran basin, in descending order, are karstic domains, slope values, precipitation, fracture (lineament) density, lithology, slope direction (aspect) and drainage.

Table 1 Categorization of the factors influencing recharge potential in the area. The data range *(a–b)* means (a to < b)

Factor	Range of effect (a–b)	Score
Precipitation (mm)	486–500	3
	500–600	4
	600–700	5
	700–800	6
	800–900	7
	900–1,000	8
	1,000–1,100	9
Fracture density (%)	0–20	2
	20–40	4
	40–60	6
	60–80	8
	>80	9
Drainage (%)	0–25	2
	25–50	4
	50–75	7
	>75	9
Karstic domains	Non-indicative development of karst	2
	Low development of karst	4
	Moderately developed karst	6
	Highly developed karst	8
	Very highly developed karst	9
Aspect	North	9
	Northeastern	9
	Northwestern	5
	Southern	1
	Southwestern	2
	Southeastern	3
	East	4
	West	4
	Flat	6
Lithology	Limestone	9
	Dolomitic limestone	7
	Marbly limestone	4
	Conglomerate	2
	Marl and salt	2
	Shale	2
	Alluvium	1
	Plain	1
Slope value (%)	0–5.5	9
	5.5–11.5	8
	11.5–17.5	7
	17.5–23.5	6
	23.5–30.5	5
	30.5–66	3

Factors influencing recharge rates

Lithology

The lithologic character of the exposed rocks is crucial in governing recharge and has strong influence on water percolation (Shaban et al. 2006). Although some investigations have ignored this factor by regarding the fracture and drainage characters as a function of primary and secondary porosity, this study includes lithology to reduce uncertainty in determining fracture density and drainage. The distribution of the lithologic formations was depicted on geological maps of 1:50,000 scale as base maps for further modifications by remote sensing; however, the majority of the exposed rocks in the study area reveal limestone, dolomitic limestone, marly limestone, shale, conglomerate and recent alluvium, from which six major categories were created. Figure 2 shows the distribution of lithology in the study area. The infiltration potential of each lithological unit in this area can be classified in terms of the influence on recharge rate. In the lithology factor, the carbonate formations have the highest score and shale and marl layers have the lowest score in influencing the basin groundwater recharge potential (Table 1).

Slope

The topographic slope is one of the major factors that affects infiltration and consequently recharge rate. Rainfall is the main source of groundwater recharge in this region. The topographic slope directly influences the recharge rate. Higher slope gradients produce a lower recharge because water runs rapidly off the surface of a steep slope during rainfall, not having sufficient time to infiltrate the surface and recharge the saturated zone. The different slopes can be classified and scored in terms of the influence on recharge rate, so that the steeper the slope, the greater the score and vice versa; in other words, the slope factor has an inverse relationship with the groundwater recharge. The slope analysis function in GIS was used to assess the variation of slope in the Saldoran basin using data from the digital terrain model (DTM) database in the area. Figure 3a illustrates the distribution of slopes in the study area.

Slope direction (aspect)

The angle of the sun is different on the slopes of the northern to the southern flank. The precipitation in this area is high,

Table 2 Effective weight of each recharge potential factor in the Saldoran basin

	Factor						
	Karstic domains	Precipitation	Drainage	Fracture density	Aspect	Slope value	Lithology
Weight	30 %	15 %	5 %	13 %	10 %	17 %	10 %

mainly in the form of snow. Residence time of the snowpack on the northern flank is greater than the southern flank of the region, so that there is slower snowmelt on the northern flank, which is indicative of a favorable environment for more recharge. North-facing slopes scored higher than the others, an aspect of the study area which is indicated in Fig. 3b.

Fracture (lineament) density

Analysis of lineaments and faults indicates groundwater flow routes and underground water storage. Depending on fault conditions and orientation, the role of faults in the control and transfer of groundwater can be neutral, positive or negative. Faults with a tensional component have greater ability to transfer water than the compression faults. Linear features, which are observed on the image or aerial photo and are attributed to rock fractures, are considered in hydrogeological studies. Linear geologic features were identified on satellite images of Landsat 7 ETM. The lineament distribution of the study area was achieved using a special application (Density Function) in the ArcGIS software. The lineament features were interpreted after plotting all of the linear signatures of different sizes and orientations regardless of their origin, on the image. An error ratio is inevitably created in this situation, because some of these features are not geologically related. To minimize the error ratio, topographic maps, with special reference to linear objects such as roads, pipelines and terraces were overlapped on the produced lineament map to eliminate all non-geologic linear features as much as possible. It can be concluded that the regions with more lineaments has more recharge potential, therefore a higher score. The lineaments of the Saldoran basin are shown in Fig. 4.

Drainage density map

Structural analysis of a drainage network helps assess the characteristics of the groundwater recharge zone, which is determined fundamentally by the underlying lithology, and thus provides an important index of the percolation rate. The extraction and analysis of the drainage network was conducted based on information from field data, topographic maps, aerial photographs and satellite images. The drainage density is significantly correlated with the groundwater recharge. In

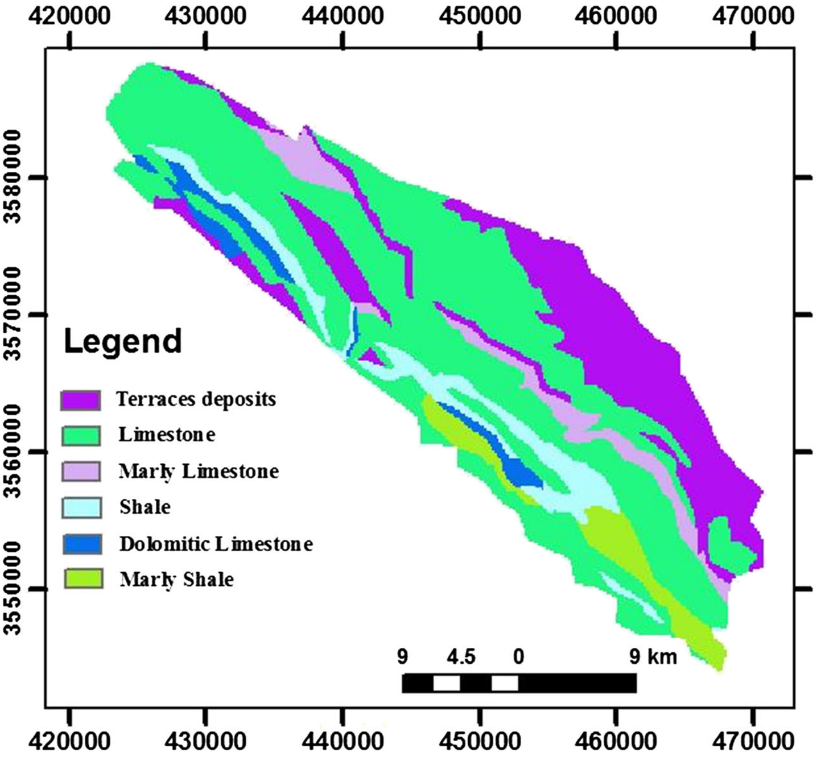


Fig. 2 Map of lithology distribution in the study area

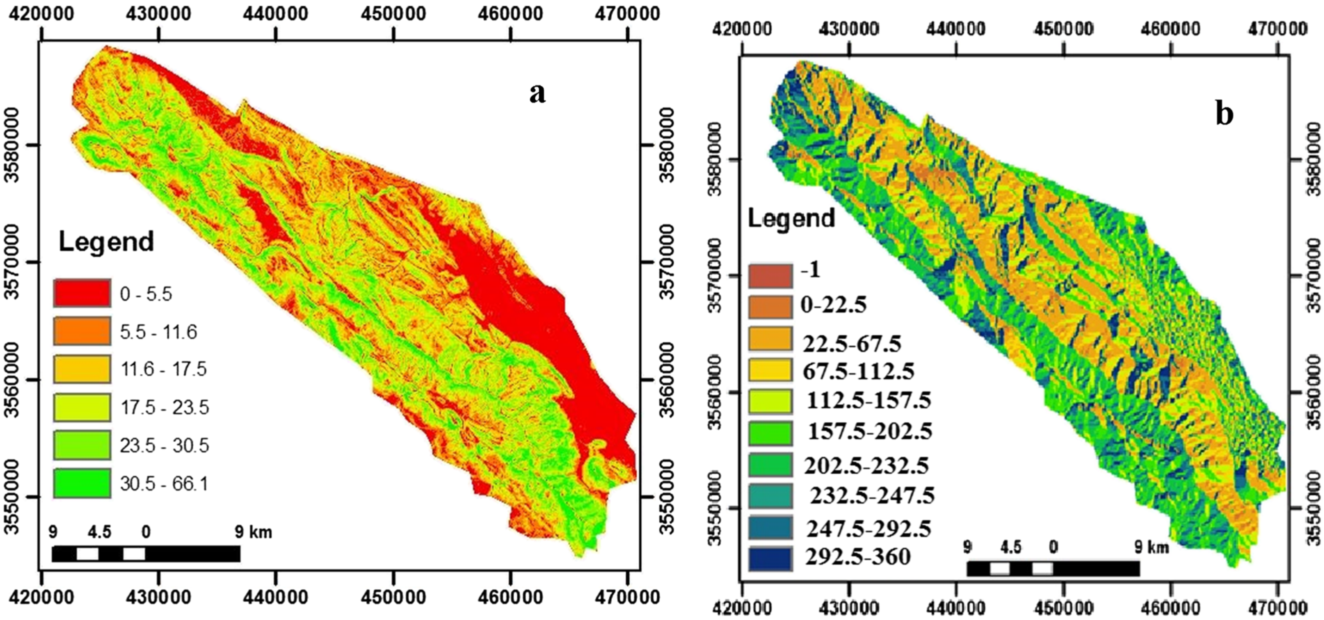


Fig. 3 Distribution map of **a** slope gradient and **b** slope direction (aspect) in the study area

this study, a drainage map of Saldoran region was created manually from the digitized topographic map on ArcGis software in order to calculate the drainage frequency. The drainage map of the study area is illustrated in Fig. 5.

Precipitation

Rainfall is one of the most important factors which influence the recharge rate into karstic formations. The amount and type of atmospheric precipitation varies depending on the climate condition and altitude. As the volume of rainfall increases, more water infiltrates the karst aquifers. The type and intensity of rainfall also affects the recharge rate, so that sudden torrential rainfall events have fewer opportunities for recharge and score low in comparison to the snowfall and slow rainfall. Regarding the importance of rainfall on the water infiltration rate, a layer of precipitation was prepared based on the implementation of the information of 11 stationsusing GIS software (Fig. 6).

Karstic domains

Normally, karst terrains are produced largely by chemical dissolution of carbonate rocks and include a variety of landforms such as solution channels, sinkholes, karren, polje and many other irregular shapes. The dissolution process often begins in and extends from existing geologic structures. Field

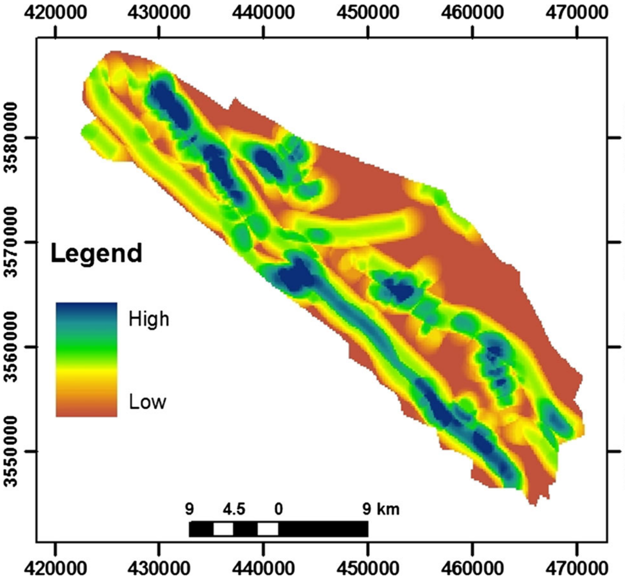


Fig. 4 Fracture (lineament) density map of the Saldoran basin

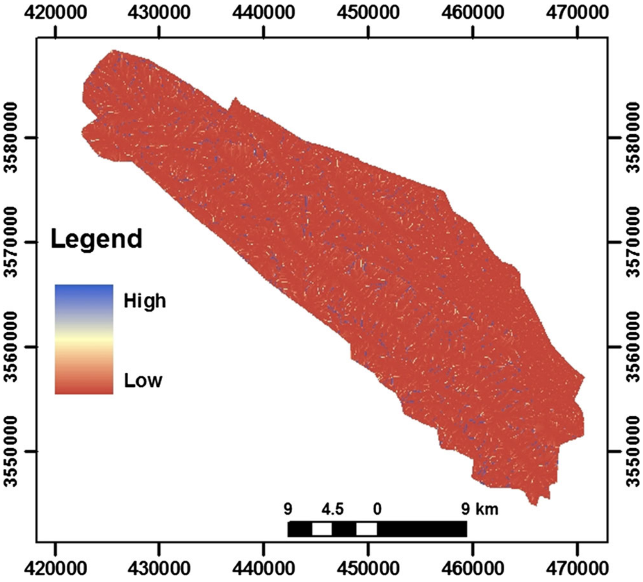
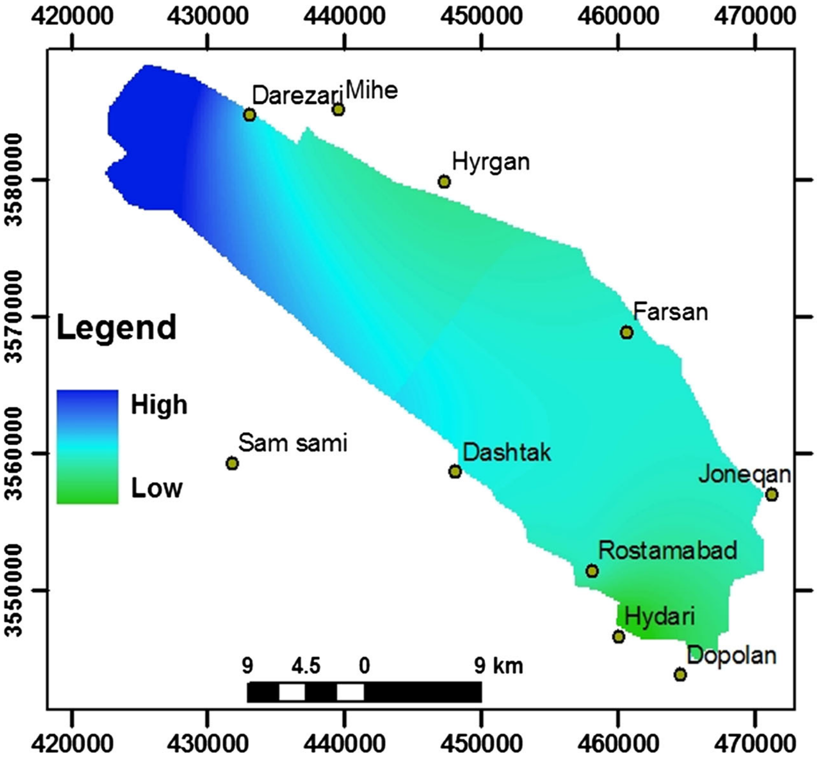


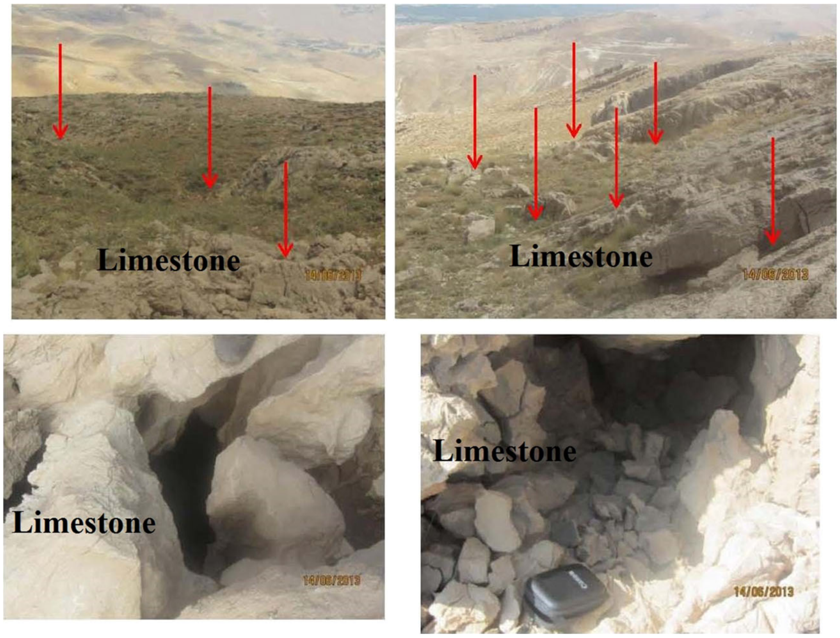
Fig. 5 Drainage map of the study area

Fig. 6 Prepared layer of precipitation based on data from 11 stations, using GIS software. Precipitation is mainly in the form of snow. Precipitation has a direct relation with elevation



investigation in the study area illustrates the importance of the surface karstic features. Four major karstic features were recognized, which are: (1) areas with developed sinkholes (Fig. 7), (2) areas with distinct polje, (3) areas with developed karst features such as karren and other surface dissolution features (Fig. 8); and (4) areas with non-apparent karst, which are covered by thick soil accumulations. The determination of the four known karstic domains was done directly based on geologic and topographic maps and field investigations. The areas with no karstification were also plotted. In addition to the preceding, remote sensing proved effective in identifying the karstic landforms. The karstic terrain in the high elevation areas could be clearly delineated from satellite and aerial photos, which was confirmed with field verification to assure the mapped data, as well as to estimate the criteria relating the karstic type domains with water recharge. Figure 9 shows the map of karstic zones according to water recharge.

Fig. 7 Developed sinkholes in the area



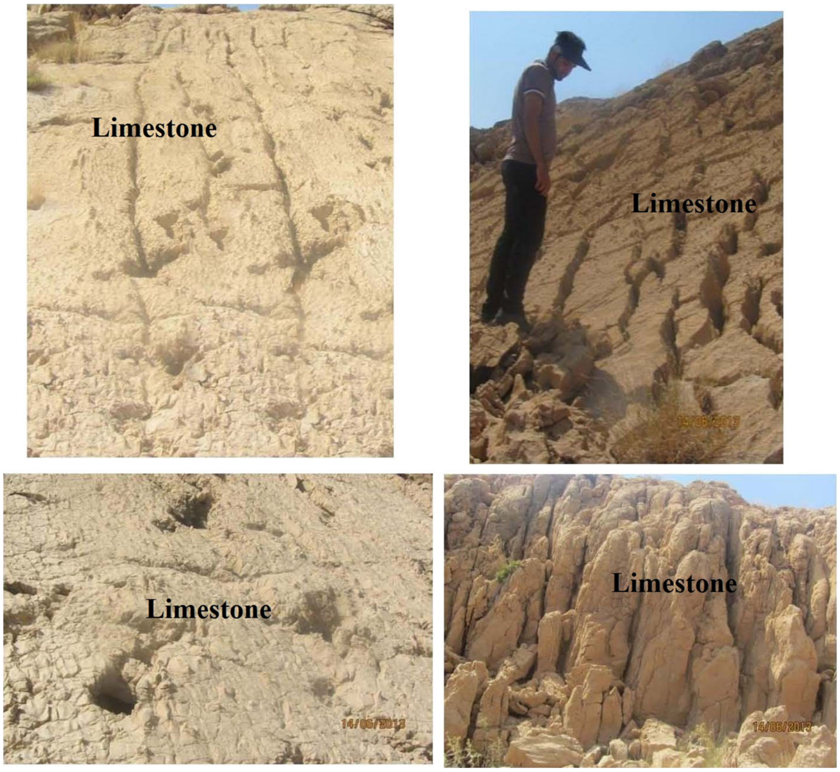


Fig. 8 Areas with developed karst features such as karren and other surface dissolution features

Weighted overlay analysis

In order to determine potential recharge zones in the study area, the previously mentioned factors influencing recharge rates were classified with a score of 1–9 based on expertise judgment. Accordingly, the classification of each factor's effect depended mainly on its influence on the recharge—where a score of 9 indicates very significant influence on recharge rate,

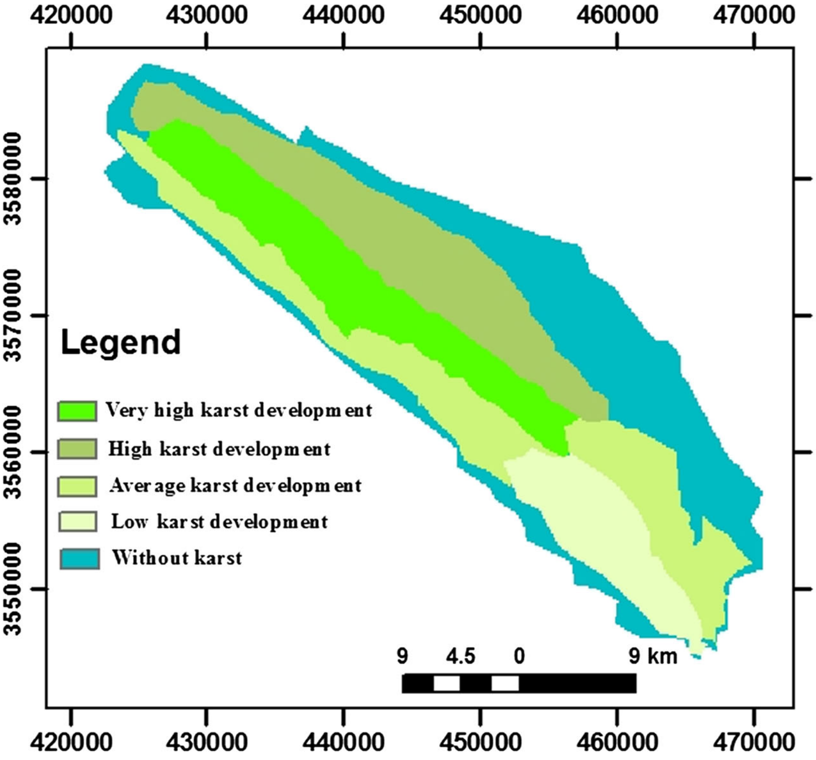


Fig. 9 Map of karstic zones in the study area

a score of 1 represents a very low influence; note these descriptive levels were, naturally, based on field observations. Table 1 shows the range of each factor and its proposed score; these factors do not have the same degree of influence on the potential recharge. Table 2 reveals the proposed weight of each factor. Assessing the effect of each factor alone on recharge potential (RP) does not yield the required complementary picture—the integration of all factors together was necessary in order to obtain a RP map; therefore, after obtaining the aforementioned weightages and scores, a weighting overlying approach was followed to incorporate these data interactively and obtain groundwater potential zones. Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs in order to create an integrated analysis. The obtained maps derived for each factor were considered as a single layer. The overlaying of these layers, each with its own weight, in a GIS system resulted in different polygons of special characteristics with respect to the overall RP for the area. The final map was produced to reveal major zones of RP with five levels (Fig. 10). The recharge percentages and area of each order which are shown in the Fig. 10 are presented in Table 3.

Water budget of Saldoran anticline

A water budget or water balance is a measurement of continuity of the water flow in a system, in which the change of storage of water with respect to time within the aquifer is equal to the difference between the input and output waters to the aquifer (Todd and Mays 2005). Evaluating the water budget of Saldoran Mountain showed that the total volume of karst water emerging from the Saldoran karst springs, namely Pire-Ghar, Sarabe-Babaheydar and Bagh-Rostam, is equal to the total annual recharge on the anticline. The total area of Saldoran outcrops is about 344 km^2. Considering the average recharge rate of 63 %, and 950 mm annual rainfall in the study area, the amount of 205 million cubic meters (MCM) water was recharged to the anticline. This almost equals the annual discharge of about 195 MCM via the karst springs; therefore, the catchment area of the already mentioned karst springs includes the whole Saldoran anticline.

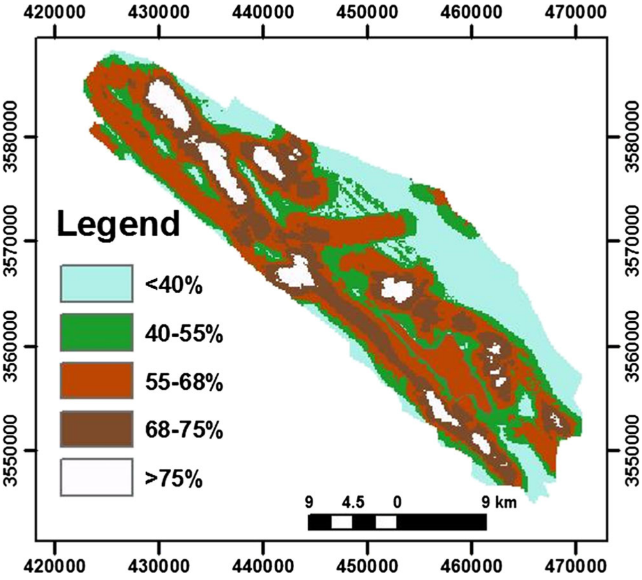


Fig. 10 Map of percentage of recharge potential zones in the study area, prepared using GIS

Table 3 Recharge percentages and area of each order in the study area

Area (km^2)	Annual recharge (%)
100	<40
40	40–55
300	55–68
149	68–75
130	>75

Calculation of the catchment area of springs

The catchment areas of the Pire-Ghar, Sarabe-Babaheydar and Bagh-Rostam springs were determined by geological and water balance methods. Locations of these springs are plotted using a Google-Earth map (Fig. 11). Using the calculated approximate catchment area, the most probable location and boundaries of the catchments were determined. In the catchment area, there must be no hydrogeological and tectonic barriers disconnecting the hydrogeological relationship between the karst aquifer and the spring; in other words, geological and tectonic settings justify the catchment area.

Pire-Ghar spring catchment area

Pire-Ghar spring emerges from the Sarvak limestone formation in the northern flank of the Saldoran anticline. Its annual discharge was 62.3 MCM during the study period. The catchment area of this spring is calculated to be about 93 km^2 based on the budget equation. The probable boundary of the catchment area was determined based on sequence stratigraphy, tectonics and morphology of the area (Fig. 12). The northern flank of Saldoran anticline, mostly consisting of Asmari and Sarvak limestone formations, is located at a higher elevation than the spring. As a result of tectonic and erosion activities, part of the catchment area of Pire-Ghar is crushed. The geological strata dip steeply to the northeast (Fig. 1); therefore, given the existence of thrust faults in the region, especially in the northern flank of the Saldoran Mountain, the groundwater flows from the entire proposed catchment area to the spring. It seems that the potential discharge of water from the northern flank of the Saldoran Anticline is more than that of the southern flank, particularly in the Sarvak formation.

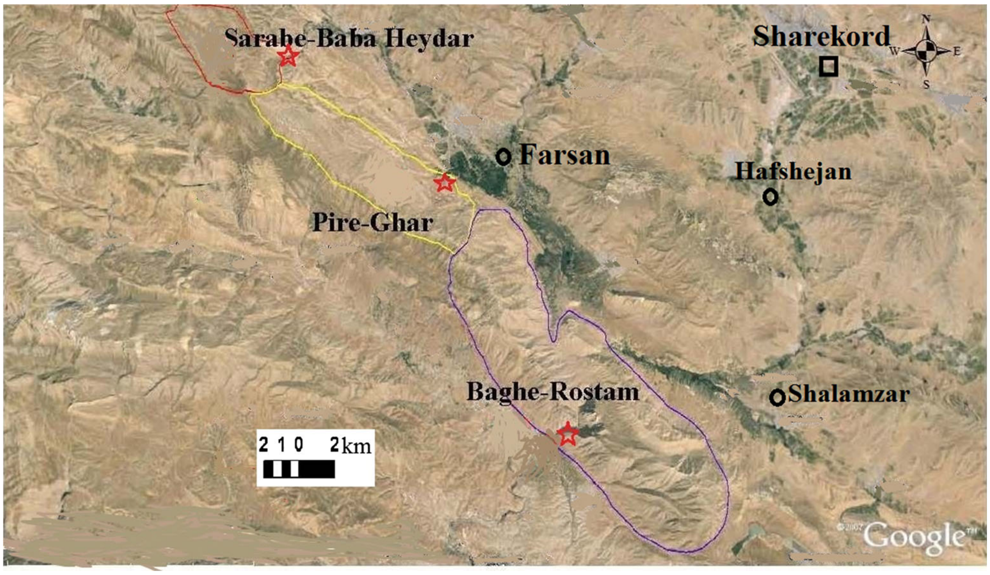


Fig. 11 Locations of the springs on Google Earth map (*red stars* are the main springs)

Sarabe-Babaheydar spring catchment area

Sarabe-Babaheydar spring, with annual discharge of 31 MCM, emerges from Asmari limestone formation in the northern flank of the Saldoran anticline. Based on the water balance calculation, about 47.5 km^2 of the catchment area belongs to this spring (Fig. 13). Based on sequence stratigraphy, the catchment area predominantly includes Asmari and Sarvak limestone formations. This spring discharges along a valley which is a result of erosion of shear fractures. The large-scale joints and tensile faults play a major role in the development and direction of water flow in the catchment area of this karst spring. At the southwest border of the catchment area, and in contact with the Sarvak formation, the impermeable layers of shale act as a hydro-dam, and thus prevent the water from moving toward the recent adjacent deposits. The eastern border of Babaheydar spring catchment is in contact with non-karst formation, whereas the western border of the catchment area is limited to the fault as a conduit, which drains water from melting snow in the mountains to the spring. In terms of hydrogeology, this fault plays the role of feeder boundary. Based on the geological field investigations, different sinkholes are identified along this fault toward the spring; additionally, a polje named "Lagharak" exists in the southwest of the catchment area, which backs up the recharge zone of the karst spring (Fig. 1).

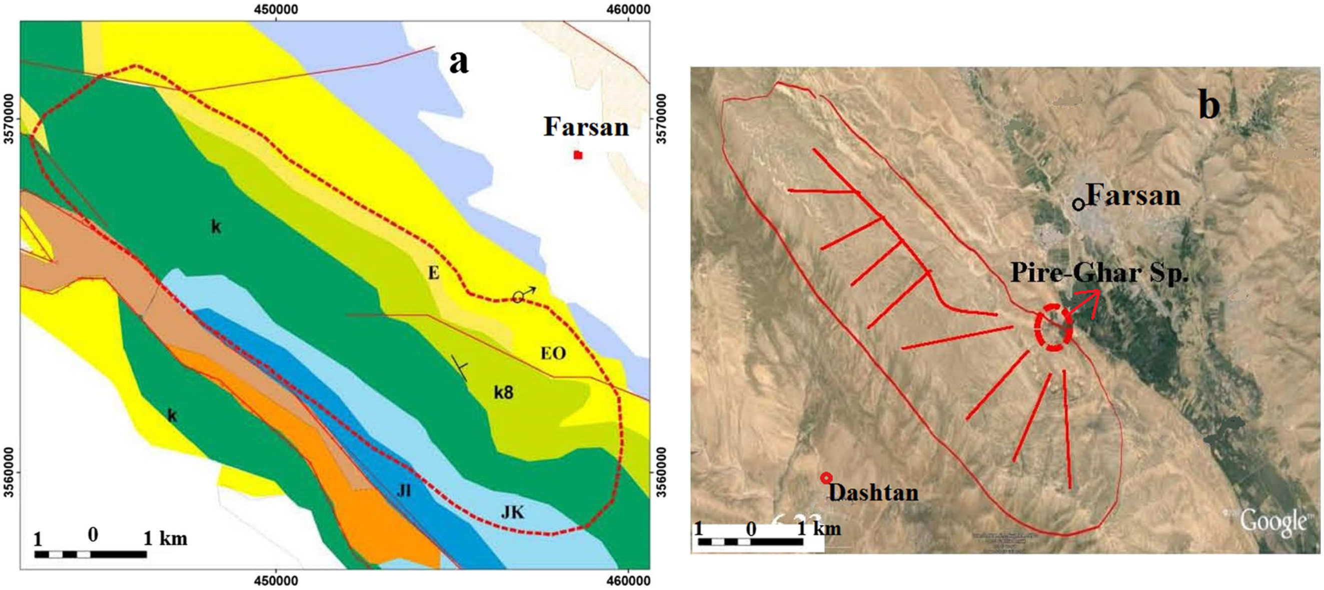


Fig. 12 Probable boundary of the Pire-Ghar spring catchment area: **a** in geological map **b** in Google Earth map

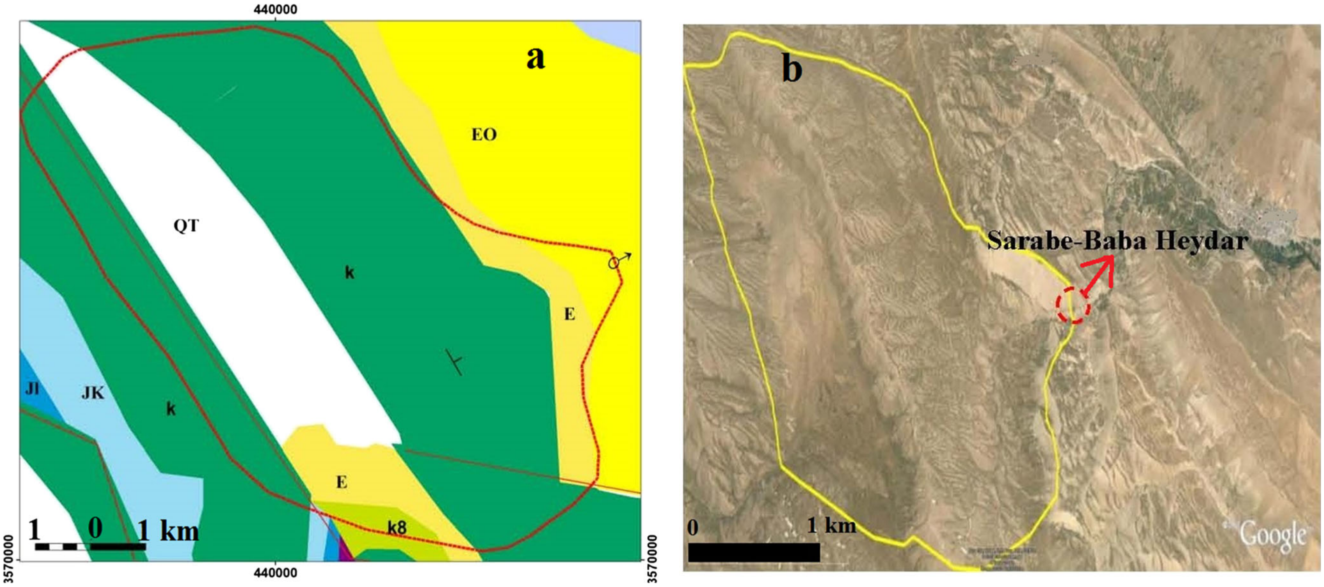


Fig. 13 Probable boundary of the Sarabe-Babaheydar spring catchment area: **a** in a geological map **b** in a Google Earth map. For legend, see Fig. 1

Baghe-Rostam spring catchment area

Baghe-Rostam spring emerges from Sarvak limestone formation and at the intersection of a major fault name "Ardal" with two other minor faults in southern flank of the Saldoran anticline. Ardal fault is a basement fault with a NW–SE direction, acting as a natural underground barrier to the emergence of Baghe-Rostam spring. Its annual discharge was 62.3 MCM during the study period. The catchment area of this spring is calculated at about 93 km^2 based on the water budget equation, while the probable boundary of the catchment area was determined based on sequence stratigraphy, tectonics and morphology of the area (Fig. 14). In terms of geology, the Sarvak Limestone is the main karst formation in the area.

Conclusions

The groundwater recharge potential map, catchment areas of Pire-Ghar, Sarabe-Babaheydar and Baghe-rostam springs, and probable boundaries of recharge areas of the Saldoran basin were determined in western Iran, using geological setting, water

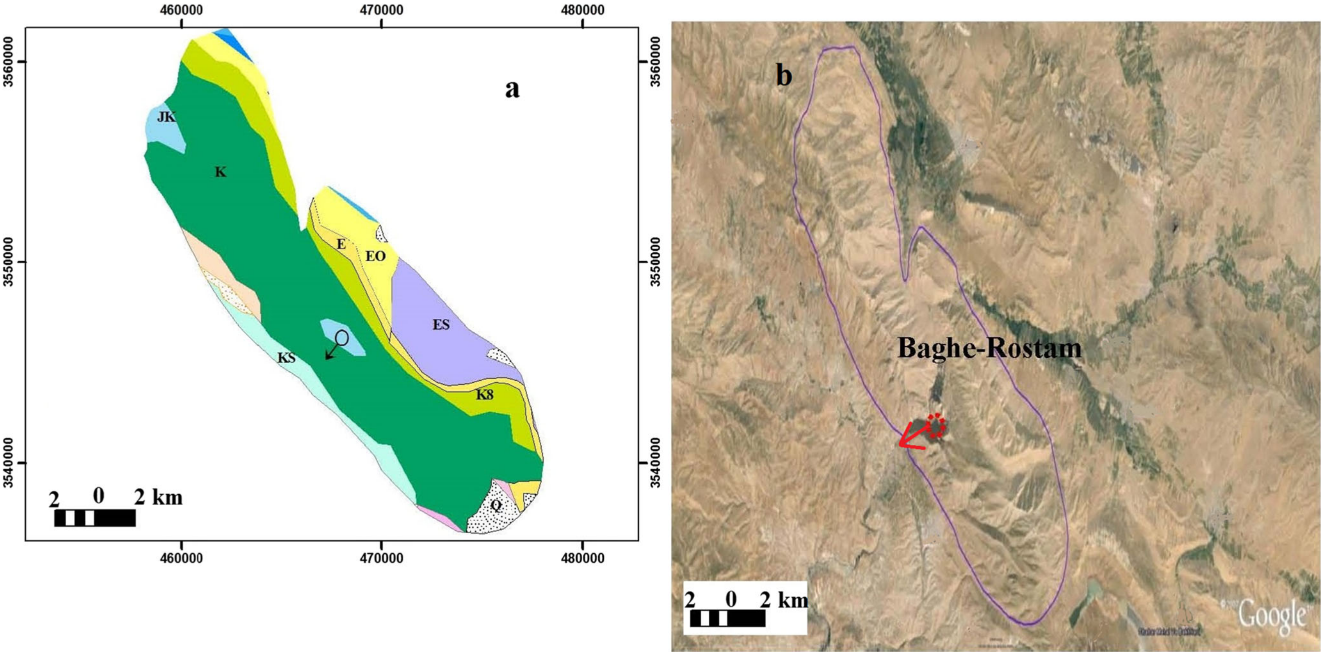


Fig. 14 Catchment area of Baghe-Rostam spring: **a** in geological map **b** in Google Earth map

balance and GIS tools. These springs are the three major karstic springs which drain the Saldoran anticline. Karst aquifers are an important groundwater resource and are highly vulnerable to contamination due to relatively fast transport and limited attenuation processes. Karst systems denote an extremely heterogeneous space medium. The dissolution produces complex networks of preferential flow pathways that are difficult to locate. The first step is to study hydrogeological setting and agricultural and environmental issues in a basin, notably those concerned with groundwater exploitation, in determining essential zones of different recharge potential. Differentiation of a spring's catchment area can be helpful to determine sources of recharge water and pollution in groundwater. In order to determine the recharge potential map of the area, seven major influencing factors on groundwater recharge rates—namely lithology, slope value and aspect, drainage, precipitation, fracture density and karstic domains—were integrated using a geographical information system. Geology maps and field verification were used to determine the weights of factors. More than 80 % of the study area is terrain that has an average ~63 % recharge rate. Finally, recharge for Pire-Ghar, Sarabe-Babaheydar and Baghe-rostam springs yielded 66, 68 and 62 %, respectively. Based on the amount of annual discharge of these springs, the recharge areas for Pire-Ghar, Sarabe-Babaheydar and Baghe-rostam springs were determined as 93, 47.5 and 204 km^2, respectively. The estimation of the recharge rate was subject to error due to uncertainties in the non-homogenous nature of the karst formation, the method of study, and limited investigation due to time and cost factors. The uncertainties may occur in estimating and measuring factors that influence the groundwater recharge rates such as the basic geology map, fracture density, slope value and aspect, and karstic domains. Despite this uncertainty, the recharge rate in the karstic system must be taken into consideration by hydrogeology-based karst investigation. It is recommended that a combination of the aforementioned methods and extra tools such as tracer test approaches, be applied for determination of catchment areas in such complex systems, thus reducing the level of uncertainty and gaining more precise information.

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