No.1 Reviewer Comments and Authors Responses

I am very much thankful to the reviewer for his/her deep and thorough review. I have revised my present research paper in the light of his/her useful suggestions and comments. I hope my revision has improved the paper to a level of his/her satisfaction. Number wise answers to his/her specific comments/suggestions/queries are as follows:

Comment-1:

- Page 2, line 26-28: In the ABSTRACT section, in the manuscript, there are many grammatical errors.

Response: The required changes were made. The changes highlighted in the manuscript with the yellow color.

Comment-2:

- Page 3-5, line 47-107: In the INTRODUCTION section, in the manuscript, there are many grammatical errors. Some sentences are not clear (Line 49-50, 91-94 and 105). There are some strange references (Line 55).

Response:

The required changes were made. The changes highlighted in the manuscript with the yellow color.

Comment-3:

- Page 5-13, line 109-230: In the METHEDOLOGY section, in the manuscript, there are many grammatical errors. Some sentences are not clear (Line 145, 197).

- Please, insert TAB 1 (Line 126) - is it referred to parameter or weight? Please, clarify. If it is referred to weight, move brackets after "weight" (Line 128)
-What the D, R, A, S, T, I, C factors name? Why in the D, R and C factors the subscript letter W is in capital? (Line 131) -Table incomplete. Net Recharge factor is missing. Please, add a column with letters referred to parameters or explicit them in the caption (as in line 141 for L factor)
- Please, pay attention to tab formatting. Move the title to the correct column (Line 148 or Table 3)
- Explicit acronym (Line 212 and 222)

Response:

The required changes were made. The changes highlighted in the manuscript with the yellow color.

Comment-4:

- Page 13-24, line 231-382: In the RESULTS AND DISCUSSION section, in the manuscript, there are many grammatical errors. Some sentences are not clear (Line 243-4, 265-6).

- Insert TAB 6 (Line 234), insert FIG 6 (Line 306), insert TAB 7(Line

311), insert TAB 8 (Line 346), insert TAB 9 (Line 348), insert TAB 10 (Line 367), and insert TAB 11(Line 371).

- Uniform maps dimensions (Line 301 or FIG 5)

- Pay attention to formatting (Line 303 or Table 6) - Too many repetition "high", try to reformulate (Line 319-325)

Response:

The required changes were made. The changes highlighted in the manuscript with the yellow color.

Comment-5:

- Page 25, line 384-400: In the CONCLUSIONS section, in the manuscript, there are many grammatical errors.

Response:

The required changes were made. The changes highlighted in the manuscript with the yellow color.

Comment-6:

- Page 29, line 479: In the REFERENCES section: pay attention to formatting

Response:

The required changes were made. This reference is a Conference Proceedings. It is written according to the journal's instructions.

Changes made based on NO.1 referee comments are highlighted in the rewritten manuscript as follows:

Contribution of the Sensitivity Analysis in Groundwater Vulnerability Assessing Using the DRASTIC and Composite DRASTIC Indexes

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ABSTRACT

The present study estimates Kerman–Baghin aquifer vulnerability by applying the DRASTIC and composite DRASTIC (CDRASTIC) indexes. The factors affecting the transfer of contamination, including the water table depth, the soil media, the aquifer media, the impact of the vadose zone, the topography, the hydraulic conductivity, and the land use, were ranked, weighted, and integrated, using a geographical information system (GIS). A sensitivity test has also been performed to specify the sensitivity of the parameters. The study results show that the topographic layer displays a gentle slope in the aquifer. The majority of the aquifer covered irrigated field crops and grassland with a moderate vegetation cover. In addition, the aquifer vulnerability maps indicate very similar results, recognizing the northwest parts of the aquifer as areas with high and very high vulnerability. The map removal sensibility analysis (MRSA) revealed the impact of the vadose zone (in the DRASTIC index) and hydraulic conductivity (in the CDRASTIC index) as the most effective parameters in the vulnerability evaluation. In both indexes, the single-parameter sensibility analysis (SPSA) showed the net recharge as the most effective factor in the vulnerability estimation. From this study, it can be concluded that vulnerability maps can be used as a tool to control human activities for the sustained protection of aquifers.

Keywords: Vulnerability; Sensitivity analyses; DRASTIC; Composite DRASTIC; Kerman–Baghin aquifer

1. Introduction

Groundwater is as a significant and principal freshwater resource in most parts of the world, especially for those in waterless and arid areas. Water quality has been given more emphasis on groundwater management (Neshat et al., 2014; Manap et al., 2013; Manap et al., 2014a; Ayazi et al., 2010). The potential groundwater's contamination by mankind operations at or near the surface of the groundwater has been supposed the major base for control of this source (Tilahun and Merkel, 2010).

The introduction of potential contaminants to a location on top of an aquifer at a specific location in an underground system is defined as groundwater vulnerability (Sarah and Patricia, 1993; Neshat et al., 2014). Groundwater vulnerability is an evaluation of the groundwater pollution relative hazard by a specific constituent. Vulnerability maps are commonly performed at a sub-basin, basin, or regional scale. They are not normally applied for site-specific evaluations including zones smaller than a few tens of square kilometers (Baalousha, 2006; Tilahun and Merkel, 2010). Different techniques have been presented to assess groundwater susceptibility with great precision (Javadi et al., 2010; Javadi et al., 2011). Mostly, these methods include analytic tools considered to relate groundwater contamination with land operations. There are three types of evaluation methods; the overlay and index, the process-based simulation and, the statistic procedures (Neshat et al., 2014; Dixon, 2004).

Overlay and index procedures affirm the incorporation of various zonal maps by allocating a numeral index. Both procedures are simple to use in the geographic information system, especially on a zonal measure. Hence, these methods are the most famous procedures applied to vulnerability estimation (Neshat et al., 2014). The most extensively used methods for the groundwater's vulnerability evaluation are GODS (Ghazavi and Ebrahimi, 2015), IRISH (Daly and Drew, 1999), AVI (Raju et al., 2014), and DRASTIC (Neshat et al., 2014; Baghapour et al., 2014; Baghapour et al., 2016).

The DRASTIC index, for the first time proposed by Aller et al (1985), it is considered one of the best indexes for the groundwater vulnerability estimation. This method ignores the influences of zonal properties. Thus, identical weights and rating values are utilized. In addition, this technique does not apply a standard validation test for the aquifer. Therefore, several investigators developed this index using various techniques (Neshat et al., 2014). The higher DRASTIC index represents the greater contamination potential and inversely. After calculating the DRASTIC index, it should be possible to identify the zones that are more prone to pollution. This index only provides a relative estimation and is not created to make a complete assessment (Baalousha, 2006).

Many studies have been conducted using DRASTIC index to estimate the groundwater vulnerability in different regions of the world (Jaseela et al., 2016; Zghibi et al., 2016; Kardan Moghaddam et al., 2017; Kumar et al., 2016; Neshat and Pradhan, 2017; Souleymane and Tang, 2017; Ghosh and Kanchan, 2016; Saida et al., 2017), however, fewer studies have used the CDRASTIC index for evaluation of the groundwater vulnerability (Baghapour et al., 2016; Baghapour et al., 2014; Secunda et al., 1998; Jayasekera et al., 2011; Shirazi et al., 2012; Jayasekera et al., 2008). Boughriba et al. (2010) utilized DRASTIC index in geographical information system environment for an estimation of the aquifer vulnerability. They provide the DRASTIC modified map prepared from total DRASTIC indexes and small monitoring network maps including two classes, high and medium. Then, authors integrated the map with the land use map to provide the contamination potential map. They reported that the new obtained groundwater vulnerability map including three various classes very high, high, and medium.

Babiker et al. (2005) used the DRASTIC index to determine prone points to contamination from human activities in the aquifer. They reported that in terms of vulnerability, the western and eastern parts of the aquifer fall in the high and medium classes, respectively. The final aquifer vulnerability map represents that the high risk of pollution is in the eastern part of aquifer due to agriculture activities. They also observed that the factor, net recharge has the biggest effect on the aquifer vulnerability, followed by the soil media, the topography, the impact of the vadose zone, and the hydraulic conductivity.

The water scarcity in Iran, with a mean annual rainfall about one-third of the world annual rainfall (Chitsazan and Akhtari, 2006; Modabberi et al., 2017) is a very critical and serious problem. Also, the groundwater reduction makes worst the previous problem. Groundwater is the only freshwater resource in the Kerman province, due to the lack of surface water. The aquifer, object of this research, is located in the central part of Kerman province in Iran. Due to recent droughts, this aquifer is placed under heavy pumping to irrigate crops, which cause gradually the drop of the water level. Moreover, recently, the use of groundwater resources has been greater than in former years. It makes the studies on the pathology and zoning the damages in groundwater undeniable. Therefore, the purpose of this research is providing the Kerman–Baghin aquifer vulnerability maps and performing the sensitivity analysis to identify the most effective factors in the vulnerability assessment.

2. Methodology

2.1. Study area

The Kerman Province covers both semiarid and waterless areas. The present study included a 2023 km^2 area (29° 47′ to 30° 31′ N latitude and 56° 18′ to 57° 37′ E longitude) located in the central part of the Kerman Province, Iran (Fig.1). The study area is mostly covered by agricultural land (Neshat et al., 2014). In the study area, the mean annual rainfall is 108.3 mm (during 2017); the highest and lowest topographic elevation is 1,980 and 1,633 m above sea level; and eventually, the mean, minimum, and maximum annual temperatures are 17°C, -12°C, and 41°C, respectively (during 2017).

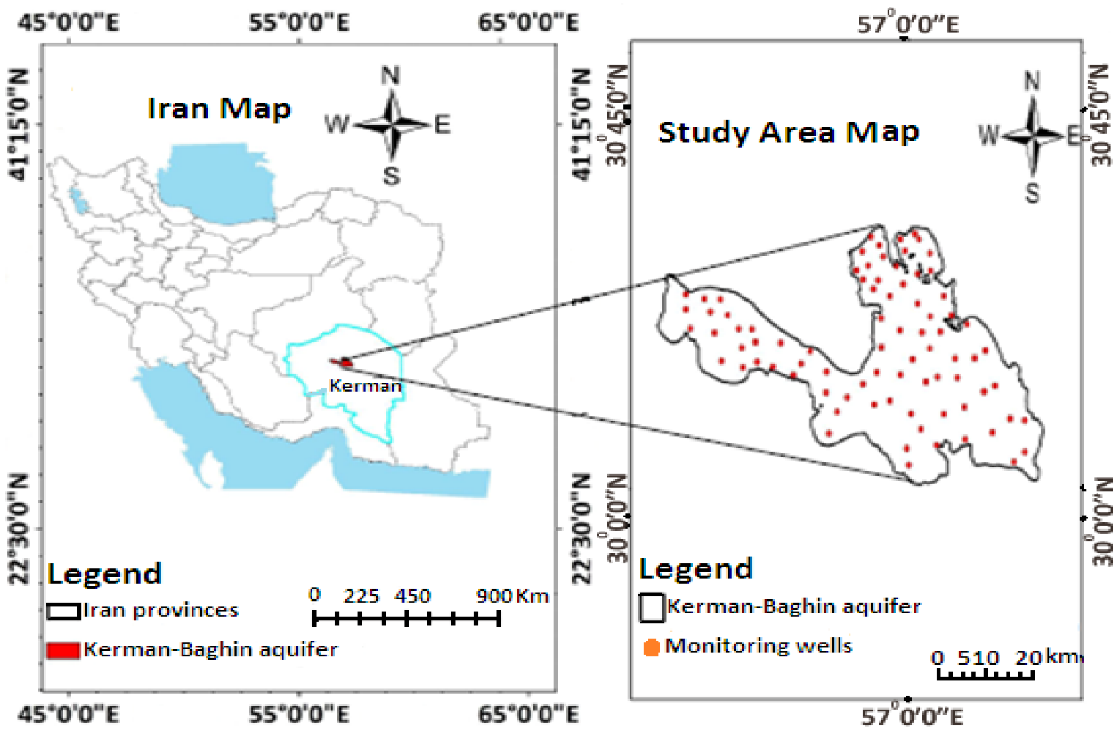

Fig. 1. Location map of the Kerman–Baghin aquifer

2.2. Computing the DRASTIC and CDRASTIC indexes

DRASTIC is a procedure developed by the United States Environmental Protection Agency (U.S EPA) to evaluate the groundwater pollution (Aller et al., 1985). Higher DRASTIC index corresponds to high vulnerability of the aquifer to pollution. Vulnerability ranges corresponding to the DRASTIC index are presented in Tab 1. In the DRASTIC index, each parameter is rated on a scale from 1 to 10 that shows the relative contamination potential of that parameter for that area. Also, in the DRASTIC index, one weight (1 to 5) is assigned to each of the parameters.

Weight values show the relative significance of the parameters with respect to each other. The DRASTIC index is obtained using the following formula (Kardan Moghaddam et al., 2017; Neshat and Pradhan, 2017):

$$\text{DRASTIC index} = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w. \quad (1)$$

In the above formula, the letters in the acronym DRASTIC comprise a short form of the effective factors in the DRASTIC index. D, R, A, S, T, I, and C are the water table depth, the net recharge, the aquifer media, the soil media, the topography, the impact of the vadose zone, and the hydraulic conductivity, respectively. Also, "r" and "w" are the rating and weight of each factor, respectively. The ratings and weights of the factors are depicted in Tab 2.

Table 1 The range of vulnerability related to the DRASTIC index

Vulnerability	Ranges
Very low	23-46
Low	47-92
Moderate	93-136
High	137-184
Very high	>185

Table 2 Rating and weight-related to DRASTIC index factors

DRASTIC parameters	Range	Rating (r)	Weight (w)
Water table depth (m)	0.0-1.5	10	5
	1.5-4.6	9	
	4.6-9.1	7	
	9.1-15.2	5	
	15.2-22.9	3	
	22.9-30.5	2	
	>30.5	1	
Net recharge	11-13	10	4
	9-11	8	
	7-9	5	
	5-7	3	
	3-5	1	

Aquifer media	Rubble and sand Gravel and sand Gravel, sand, clay, and silt Sand and clay Sand, clay, and silt	9 7 5 4 3	3
Soil media	Rubble, sand, clay, and silt Gravel and sand Gravel, sand, clay, and silt Sand Sand, clay, and silt clay and silt	9 7 6 5 3 2	2
Topography or slope (%)	0-2 2-6 6-12 12-18 >18	10 9 5 3 1	1
The impact of the vadose zone	Rubble, sand, clay, and silt Gravel and sand Gravel, sand, clay, and silt Sand, clay, and silt	9 7 5 3	5
Hydraulic conductivity (m/day)	0-4.1 4.1-12.2 12.2-28.5 28.5-40.7 40.7-81.5	1 2 4 6 8	3

To get the CDRASTIC index, an additional factor (land use) is added to the above formula. Thus, the CDRASTIC index was obtained as follows:

$$\text{CDRASTIC index} = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w + L_r L_w. \quad (2)$$

In the above formula, L_w and L_r are the relative weight and rating related to the land use factor, respectively. Ratings and weightings applied to the pollution potential, which are related to the land use factor based on the CDRASTIC index, are indicated in Tab 3. The CDRASTIC formula final outputs are ranged from 28 to 280. Vulnerability ranges based on the CDRASTIC index are presented in Tab 4.

Table 3 Ratings and weighting applied to the pollution potential related to the land use factor based on the CDRASTIC index

Land use	Rating	Weight
Irrigated field crops + Urban areas	10	
Irrigated field crops + Grassland with poor vegetation cover + Urban areas	9	
Irrigated field crops + Grassland with moderate vegetation cover + Urban areas	8	
Irrigated field crops	8	
Irrigated field crops + Fallow land + Grassland with poor vegetation cover	7	
Irrigated field crops + Grassland with poor vegetation cover	7	
Irrigated field crops + Grassland with moderate vegetation cover	6	
Irrigated field crops + Rocky + Urban areas	5	**5**
Irrigated field crops + Grassland with poor vegetation cover + Woodland	5	
Irrigated field crops + Woodland	5	
Irrigated field crops + Rocky	4	
Fallow land	3	
Fallow land + Grassland with poor vegetation cover	3	
Fallow land + Grassland with moderate vegetation cover	3	
Grassland with poor vegetation cover	2	
Grassland with moderate vegetation cover	2	
Grassland with moderate vegetation cover + Woodland	1	
Sand dune +Grassland with moderate vegetation cover	1	
Sand dune	1	

Table 4 Vulnerability ranges related to the CDRASTIC index

Vulnerability	Ranges
Very low	<100
Low	100-145
Moderate	145-190
High	190-235
Very high	≥235

2.3. Water table depth

The water table depth factor is the distance of water table from the Earth's surface, in a well (Baghapour et al., 2016). 83 wells in the Kerman–Baghin aquifer were utilized to obtain this factor. The interpolation procedure was used to provide a raster map of the water table depth factor, which was categorized based on Tab 2.

2.4. Net recharge

Net recharge is the amount of runoff that permeates into the ground and reaches the groundwater surface (Singh et al., 2015; Ghosh and Kanchan, 2016). This research uses the Piscopo method (Chitsazan and Akhtari, 2009) to provide the net recharge layer for the Kerman–Baghin aquifer according to the following equation and Tab 5:

$$\text{Net recharge factor} = \text{slope } (\%) + \text{ rainfall} + \text{soil permeability}. \quad (3)$$

In the above equation, the percentage of slope was calculated from a topographical map, using a digital elevation model. Also, a soil permeability map was created using the Kerman–Baghin aquifer soil map (with scale 1:250000) and the drilling logs of the 83 wells. In the end, a map of the area's rainfall rate was compiled based on the annual average precipitation. Ratings and weights of the net recharge factor are illustrated in Tab 5.

Table 5 Weight, rating, and range of the net recharge parameter

Slope (%)		Rainfall		Soil permeability		Net Recharge		
Range (%)	**Factor**	Range (mm/year)	**Factor**	Range	**Factor**	Range (cm/year)	**Rating**	**Weight**
<2	4	>850	4	High	5	11-13	10	
2-10	3	700-850	3	Moderate to high	4	9-11	8	
10-33	2	500-700	2	Moderate	3	7-9	5	4
>33	1	<500	1	Low	2	5-7	3	
				Very low	1	3-5	1	

2.5. Aquifer media

Aquifer media parameter controls the path of groundwater streams in the aquifer (Aller et al., 1985; Singh et al., 2015). To obtain this layer, the 83 well's drilling log data were used. The data were gathered from the Kerman Regional Water Office (KRWO). The range of the aquifer media layer is shown in Tab 2.

2.6. Soil media

The soil media has a considerable effect on the amount of water surface that can penetrate into the aquifer. Therefore, where the soil layer is thick, the debilitation processes such as absorption, filtration, degradation, and evaporation may be considerable (Singh et al., 2015). A soil media raster map was provided using the Kerman–Baghin aquifer soil map and the well's drilling logs.

2.7. Topography

The topography controls the residence time of water inside on the soil and the degree of penetration (Singh et al., 2015). For obtain this layer, the percentage of the slope was provided from the topographical map, using a digital elevation model. The data were gathered from the KRWO. The range of the topographic layer is presented in Tab 2.

2.8. The impact of the vadose zone

The vadose zone is the unsaturated area located between the topographic surface and the groundwater level (Singh et al., 2015). It plays a considerable role in decreasing groundwater contamination by pollutant debilitation processes such as purification, chemical reaction, and dispersal (Shirazi et al., 2012). In order to prepare this layer, the wells drilling log data were used. The data were gathered from the KRWO. The impact range of the vadose zone layer is depicted in Tab 2.

2.9. Hydraulic conductivity

The hydraulic conductivity refers to the capability of the aquifer to transfer water. The high hydraulic conductivity areas demonstrate a high potential for groundwater contamination (Singh et al., 2015; Aller et al., 1985). To prepare this layer, data derived from pumping tests of wells were used. The range of the hydraulic conductivity layer is shown in Tab 2.

2.10. Land use

Land use influences groundwater resources via variation in recharge amount and by changing freshwater demands for water. Land use is obligatory since it is required by the CDRASTIC index. The Indian remote sensing satellite information was utilized to providing land use raster map. The weight and rating related to the land use layer are presented in Tab 3.

2.11. Sensitivity Analyses

One of the main advantages of the DRASTIC index is the evaluation performance because of high number of input data are used, this allows to restrict the effects of errors on the final results. Nevertheless, some investigators, like Babiker et al. (2005), Barber et al. (1993), and Merchant (1994), reported that similar results could be obtained using fewer data and lower costs. The unavoidable subjectivity related to the choice of the seven factors, ranks, and weights utilized to calculate the vulnerability index has also been criticized. Therefore, in order to eliminate the aforementioned criticisms, two sensitivity analyses were performed as follows (Napolitano and Fabbri, 1996):

A. Map removal sensibility analysis (MRSA)

MRSA value indicates the vulnerability map sensibility to removal one or more maps from the suitability analysis. MRSA is calculated as follows (Babiker et al., 2005; Martínez-Bastida et al., 2010; Saidi et al., 2011; Modabberi et al., 2017):

$$S = \left[\left|\frac{\frac{V}{N} - \frac{V'}{n}}{V}\right|\right] \times 100 \qquad (4)$$

S is the sensibility value expressed in terms of variation index, V is the intrinsic vulnerability index (real vulnerability index) and V′ is the intrinsic vulnerability index after removal of factor

X, N and n are the numbers of data factors utilized to calculate V and V′, respectively (Babiker et al., 2005; Martínez-Bastida et al., 2010; Saidi et al., 2011; Modabberi et al., 2017).

B. Single-parameter sensibility analysis (SPSA)

SPSA was presented by Napolitano and Fabbri (1996) for the first time. This test shows the effect of each of the DRASTIC factors in the final vulnerability index. Using this test derived from equation 5, the real and effective weight of each factor, compared to the theoretical weight assigned by the analytical model was calculated (Babiker et al., 2005; Martínez-Bastida et al., 2010; Saidi et al., 2011; Modabberi et al., 2017).

$$W = \left[\frac{P_r P_w}{V}\right] \times 100 \qquad (5)$$

Where, W is the effective weight of each factor. P_r and P_w are the rank and weight assigned to factor P, respectively. V is the intrinsic vulnerability index (Martínez-Bastida et al., 2010; Babiker et al., 2005; Saidi et al., 2011; Modabberi et al., 2017).

3. Results and discussion

3.1. DRASTIC and CDRASTIC parameters

Based on the data shown in Tab 2, the assigned rating of water table depth varies from 1 to 10. In addition, based on the results presented in Tab 6, the water table depth in the aquifer varies from 4.6 to >30.5 m (rating 1 to 7). Around 27.55% of the aquifer has a depth greater than 30.5 m, and 66.16 % of the aquifer has a depth ranging from 9.1 m and 30.5 m. Less than 7% has a depth between 4.6 m and 9.1 m. The Kerman–Baghin aquifer rated map of water table depth factor is presented in Fig 2(A). According to Fig 2(A) and Tab 6, the minimum impact of the water table depth parameter on aquifer vulnerability occurs in the central parts (6.39%), whereas the maximum impact occurs in the north, south, northwest, and southeast parts (27.55%).

According to the results presented in Tab 6, 75.81% of the aquifer has a net recharge value in the range of 7 to 9 cm/year. 11.74% of the aquifer has a net recharge value between 9 and 11 cm/year. The Kerman–Baghin aquifer rated map of the net recharge parameter is shown in Fig 2(B). According to Piscopo's method, the Kerman–Baghin aquifer was divided into three classes, with regards to the net recharge factor. The highest net recharge value was seen in the north, northeast, south, southwest, parts of the northwest, parts of the center, and parts of the southeast (75.81%), whereas the least net recharge value appeared in parts of the northwest and center (11.74%), as shown in Fig 2(B) and Tab 6.

As observed in Tab 6, the majority of the Kerman–Baghin aquifer media is composed of sand, clay, and silt (75.21%). The Kerman–Baghin aquifer rated map of aquifer media is presented in Fig 3(A). Parts of the aquifer in the north, northwest, northeast, center, and southeast are composed of sand, clay, and silt. Parts of the aquifer in the northwest are composed of rubble and sand (5.58%). Parts of the aquifer in the south and northwest are composed of gravel and sand (8.95%), and gravel, sand, clay, and silt (10.26%).

The Kerman–Baghin aquifer rated map of the soil media parameter is presented in Fig 3(B). The soil map depicts six different classes of the soil. The highest rank (rank = 9) was assigned to rubble, sand, clay, and silt (a combination of rubble, sand, clay and silt soils). Also, the lowest rank (rank = 2) was assigned to clay and silt (a combination of clay and silt soils). Most of the aquifer soil media is covered with silt, sand, and clay (about 80%).

The Kerman–Baghin aquifer rated map of the topography parameter is indicated in Fig 4(A). The topographical layer shows a gentle slope (0 to 6%) over most of the aquifer, hence gaining ranks of 9 and 10. A slope range of 0 to 2% includes 34.72% of the study area, and its rating (slope range = 0–2%) is 10. Also, 65.28% of the aquifer has a slope range of 2 to 6% (parts of the northwest) as shown in Fig 4(A) and Tab 6. As the gradient increases, the runoff increases as well (Israil et al., 2006) leading to less penetration (Jaiswal et al., 2003). Based on Madrucci et al. (2008), the gradients higher than 35° are considered restrictions on groundwater desirability because of the lack of springs.

The Kerman–Baghin aquifer rated map of the impact of the vadose zone parameter is indicated in Fig 4(B). According to the results, the soil with a rank of 5 (gravel, sand, clay, and silt) is more effective on aquifer vulnerability (35.47%). Other various types of soils such as sand, clay, and silt (parts of the north, northeast, south, and southeast), gravel and sand (parts of the center and northwest), and rubble, sand, clay, and silt (parts of the northwest) cover 34.24%, 20.39%, and 9.9% of the aquifer, respectively, as shown in Fig 4(B) and Tab 6. Sandy soil is effective on groundwater occurrence because of the high rate of penetration (Srivastava and Bhattacharya, 2006). However, clay soil is arranged poorly because of the low infiltration (Manap et al., 2014b).

The Kerman–Baghin aquifer rated map of the hydraulic conductivity parameter is presented in Fig 5(A). The hydraulic conductivity factor shows high variability. Our study results show that the hydraulic conductivity parameter of the Kerman–Baghin aquifer varied from 0 to 81.5 m/day. The potential for groundwater contamination greater in zones with high hydraulic conductivity (38.27%). As shown in Fig 5(A) and Tab 6, 29.51%, 23.93%, 5.98%, and 2.31% of the study areas have hydraulic conductivity in the ranges of 0 to 4.1 m/day, 12.2 to 28.5 m/day, 28.5 to 40.7 m/day, and 40.7 to 81.5 m/day, respectively.

The Kerman–Baghin aquifer rated map of the land use parameter is presented in Fig 5(B). Our results show that the majority of the Kerman–Baghin aquifer is covered with irrigated field crops and grassland with moderate vegetation cover (20.45%). Less than 4% of the study area is irrigated field crops and urban areas (3.61%), and 58.47% of the study area is irrigated field crops with urban areas, grassland with poor and moderate vegetation cover, fallow land, woodland, and rocky ground. In addition, 10.17% of the study area is fallow land with poor grassland and moderate vegetation cover, and 13.72% of the study area is sand dunes with poor grassland and moderate vegetation cover and woodland as shown in Fig 5(B) and Tabs 3 and 6.

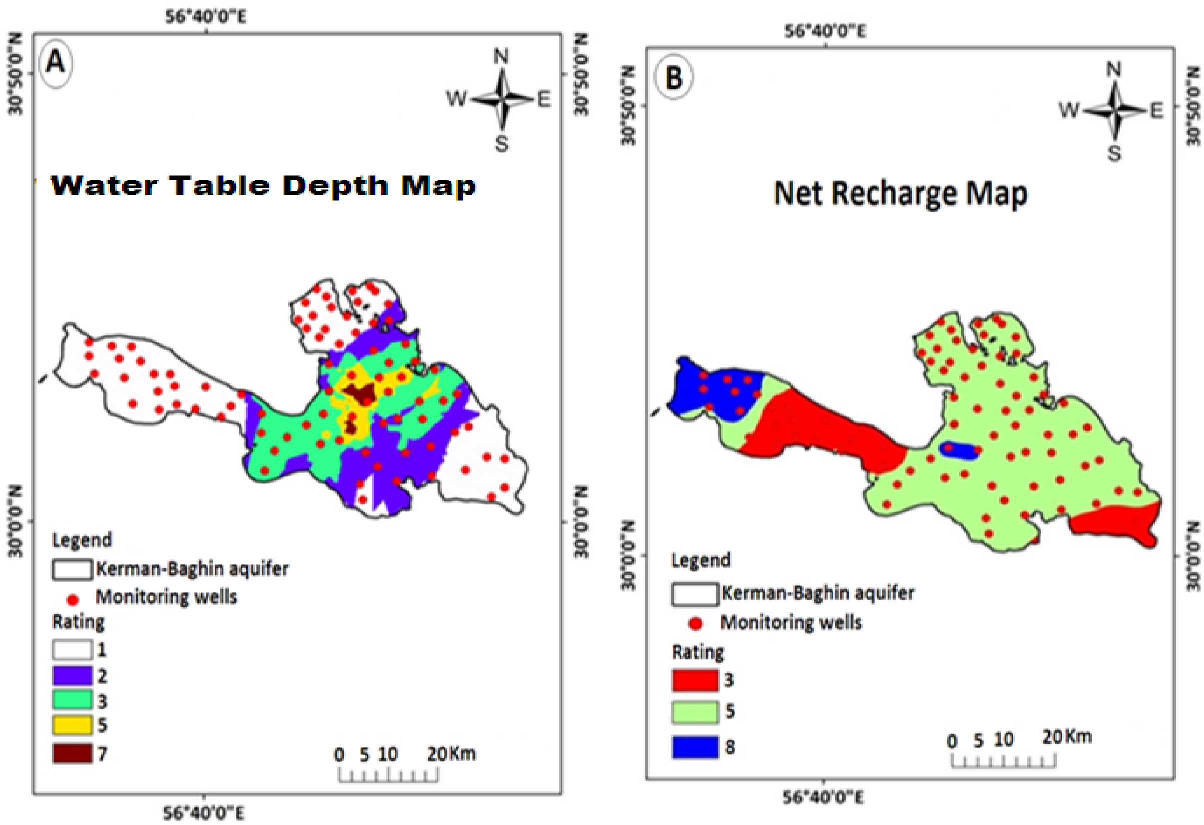

Fig. 2. Kerman–Baghin aquifer rated maps of A) water table depth and B) net recharge

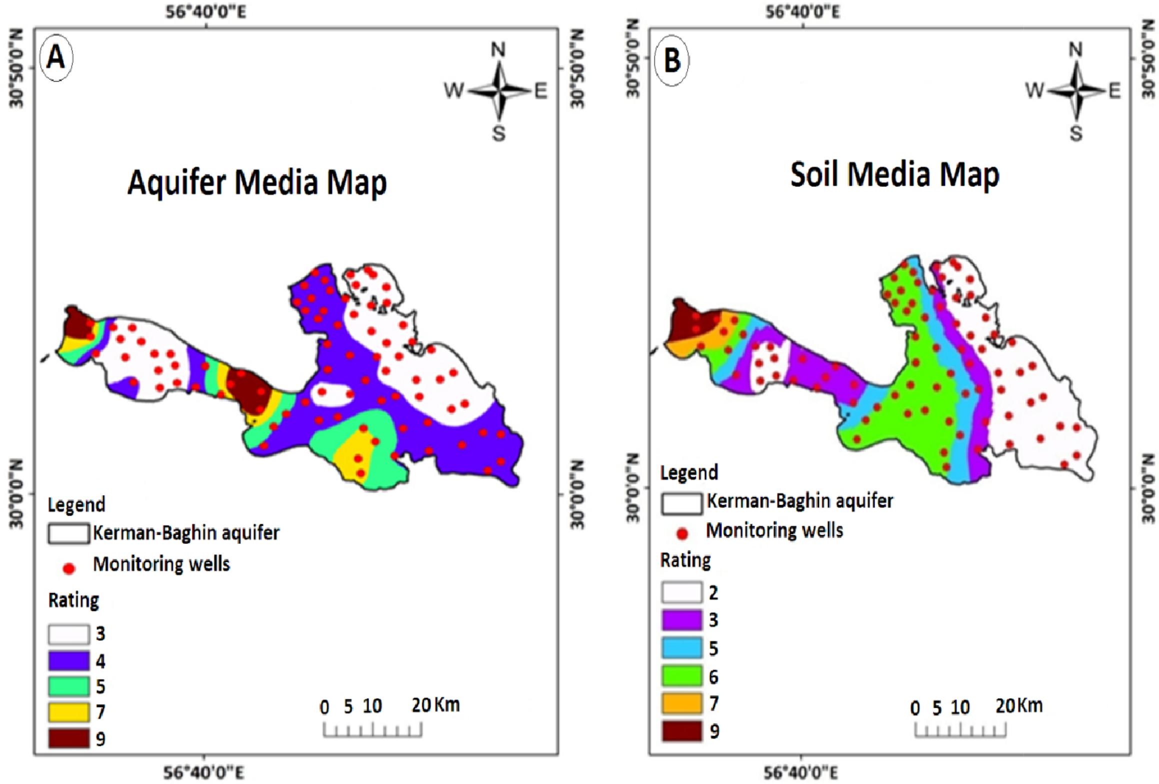

Fig. 3. Kerman–Baghin aquifer rated maps of A) aquifer media and B) soil media

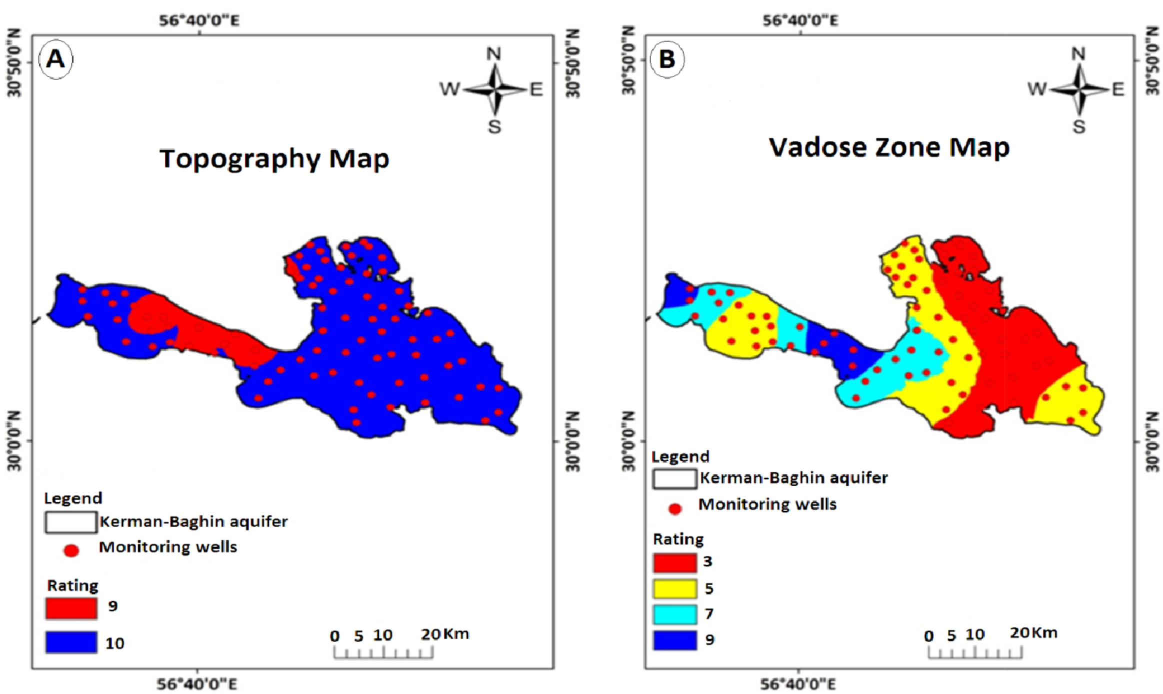

Fig. 4. Kerman–Baghin aquifer rated maps of A) topography and B) vadose zone

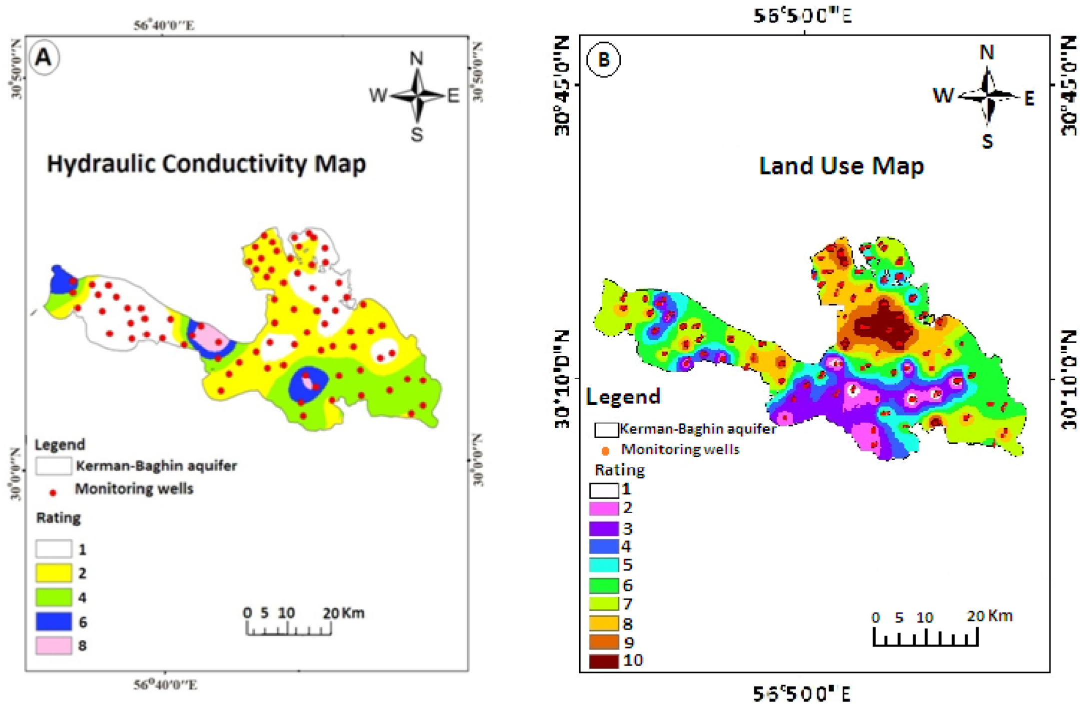

Fig. 5. Kerman–Baghin aquifer rated maps of A) hydraulic conductivity and B) land use

Table 6 The area of rating (km^2 and %) of the DRASTIC and CDRASTIC parameters

DRASTIC and CDRASTIC indexes parameters	Rating	Area (km^2)	Area (%)	The aquifer geographic directions covered by the respective rating in the parameters rated maps
Water table depth	1	557.73	27.55	Parts of the north, south, northwest, and southeast
	2	472.18	23.34	Parts of the north, south, and center
	3	469.78	23.29	Parts of the center
	5	395.00	19.53	Parts of the center
	7	129.14	6.39	Parts of the center
Net recharge	3	252.04	12.45	Parts of southeast, and northwest
	5	1534.15	75.81	North, northeast, south, southwest, and parts of the northwest, center, southeast
	8	237.6	11.74	Parts of the northwest and center
Aquifer media	3	743.18	36.72	Parts of the north, northwest, northeast, and center
	4	779.01	38.49	Parts of the north, northwest, southeast, and center
	5	207.81	10.26	Parts of the south, and northwest

	7	181.02	8.95	Parts of the south, and northwest
	9	112.76	5.58	Parts of the northwest
Soil media	2	658.5	32.53	Parts of the north, northwest, northeast, and southeast
	3	399.72	19.75	Parts of the north, northwest, south, and center
	5	297.44	14.69	Parts of the north, northwest, south, and center
	6	538.77	26.62	Parts of the northwest, center, and southwest
	7	67.56	3.33	Parts of the northwest
	9	61.79	3.08	Parts of the northwest
Topography	9	702.74	34.72	North, northwest, northeast, south, southeast, southwest, and center
	10	1321.07	65.28	parts of the northwest
The impact of the vadose zone	3	692.87	34.24	Parts of the north, northeast, south, and southeast
	5	717.91	35.47	Parts of the north, northwest, south, southeast, and center
	7	412.49	20.39	Parts of the center, and northwest
	9	200.53	9.9	Parts of the northwest
Hydraulic conductivity	1	597.11	29.51	Parts of the northeast, northwest, southeast, and center
	2	774.52	38.27	parts of the northwest, south, southeast, and center
	4	484.17	23.93	Parts of the northwest, south, and southeast
	6	120.99	5.98	Parts of the south, and northwest
	8	46.7	2.31	Parts of the south, and northwest
Land use	1	112.48	5.56	Parts of the south
	2	165.02	8.16	Parts of the south
	3	205.65	10.17	Parts of the south, and center
	4	357.06	17.64	Parts of the south, southwest, northwest, and center
	5	234.86	11.61	Parts of the southeast, northwest, and center
	6	413.86	20.45	Parts of the southeast, northwest, northeast, and center

7	182.63	9.02	Parts of the north, northwest, and northeast
8	169.4	8.37	Parts of the north, northwest, and northeast
9	109.42	5.41	Parts of the north, northwest, and northeast
10	73.09	3.61	Parts of the north

3.2. DRASTIC and CDRASTIC vulnerability indexes

The Kerman–Baghin aquifer vulnerability map using DRASTIC and CDRASTIC indexes is shown in Fig 6. In the studied aquifer, the vulnerability falls under very high, high, moderate, low, and very low vulnerable areas. It is found that in both indexes, the parts of north, northeast, northwest, south, southwest, southeast and center come under low and very low vulnerability. This can be attributed to low water depth, hydraulic conductivity, and net recharge characterizing these aquifer areas; an other reason might be that the aquifer media mostly are mostly clay, sand and silt soils. The area of the vulnerability, identified by investigated indexes, is illustrated in Tab 7. Low and very low vulnerable zones cover 25.21% and 38.31%, respectively, of the Kerman–Baghin aquifer using the DRASTIC index. Very low and low vulnerable zones cover 24.95% and 40.41%, respectively, using the CDRASTIC index. This is primarily due to water table depth and relatively low permeability of the vadose zone in such aquifers (Colins et al., 2016). Around 26 % of the studied aquifer has moderate groundwater pollution potential, using DRASTIC and CDRASTIC indexes. This does not mean that such areas are without pollution but it is relatively prone to pollution when compared with other areas (Colins et al., 2016). From the DRASTIC index values, it was noticed that 10.4% of the study aquifer is under high (8.46%) and very high (1.94%) vulnerability. The results of the study showed that 8.75% of the aquifer is in the ranges of 190 to 235 and greater than 235 in the CDRASTIC index (Tab 7). The vulnerability maps according to these two indexes indicated very same findings, showing the northwest portion of the aquifer as the high and very high vulnerable zones. The high vulnerability can be attributed to great water depth, hydraulic conductivity, and net recharge in these aquifer areas. In addition, this can due to the great slope in this area.

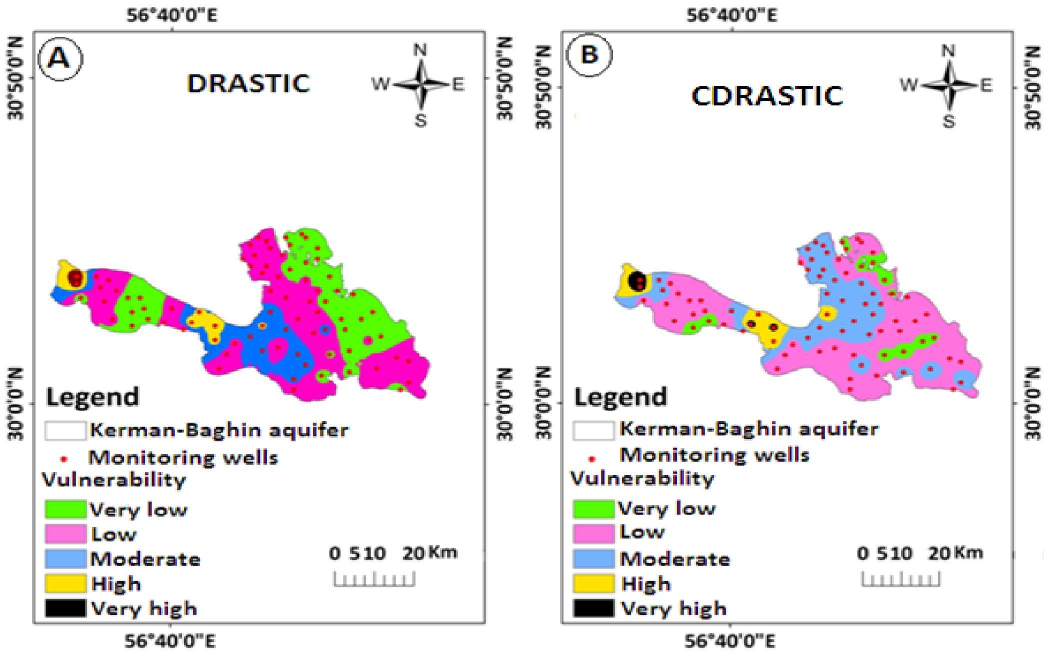

Fig. 6. The vulnerability maps of the Kerman–Baghin aquifer by DRASTIC and CDRASTIC indexes

Table 7 The area of vulnerability (km^2 and %) identified by DRASTIC and CDRASTIC indexes

Vulnerability	DRASTIC				CDRASTIC			
	Ranges	Area (km^2)	Area (%)	The aquifer geographic directions covered by the respective vulnerability	Ranges	Area (km^2)	Area (%)	The aquifer geographic directions covered by the respective vulnerability
Very low	23-46	510.25	25.21	Parts of the south, north, northwest, and northeast	<100	505.02	24.95	Parts of the southeast, north, northwest, and northeast
Low	47-92	775.14	38.31	Parts of the south, southwest, southeast, north, northwest, northeast, and center	100-145	817.70	40.41	Parts of the south, southwest, southeast, north, northwest, northeast, and center
Moderate	93-136	527. 85	26.08	Parts of the south, southwest, northwest, and center	145-190	524.06	25.89	Parts of the south, southwest, southwest, northwest, and center
High	137-184	171.02	8.46	Parts of the northwest	190-235	126.91	6.28	Parts of the northwest and center
Very high	>185	39.23	1.94	Parts of the northwest	≥235	49.79	2.47	Parts of the northwest

3.3. The sensitivity of the DRASTIC model

The MRSA, the DRASTIC index, is performed by eliminating one layer data at a time as indicated in Tab 8. The results showed a high variation in vulnerability index when the impact of the vadose zone factor was removed, so that, the average variation index is 1.88%. This shows that this factor is more effective in vulnerability assessment using the DRASTIC index. When this parameter is removed from the overlay process, this leads to a significant decrease in vulnerability index. This could be due to the high theoretical weight assigned to this factor (weight = 5). These findings are similar to those obtained by Dibi et al. (2012) who have shown that, in addition to this parameter, topography, net recharge, and water table depth have a high impact on the vulnerability index. Also, in Samake et al. (2011), the impact of the vadose zone and the hydraulic conductivity parameters had a considerable impact on the vulnerability index, that appears to have a moderate sensitivity to the deletion of water table depth (1.48%), net recharge (1.36%), and hydraulic conductivity (1.25%) parameters. The minimum menu variation index was achieved after eliminating the aquifer media factor (0.44%), as indicated in Tab 8.

For the estimation of the individual factors effect towards aquifer vulnerability, the SPSA is performed. The results summaries of SPSA in the DRASTIC index are shown in Tab 9. The SPSA compares the effective weights and theoretical weights. The average value of the effective weight of the net recharge factor is 43.26% and its theoretical weight (%) is 17.4%. This shows that this factor is more effective in vulnerability assessment using the DRASTIC index. The results reported by other studies (Babiker et al., 2005; Doumouya et al., 2012) are similar to those of the present study. The impact of the vadose zone and water table depth parameters has high theoretical weights (21.74%); they have been dedicated with an effective weight with average value such as 8.33% and 25.55%. The remaining factors show an average value of the effective weights of 14.91% (aquifer media), 9.89% (soil media), 11.35% (topography), and

7.01% (hydraulic conductivity). The theoretical weights assigned to the water table depth, net recharge, topography, and hydraulic conductivity parameters are not in agreement with the effective weight. The highest and lowest impact on aquifer vulnerability was related to the net recharge and hydraulic conductivity parameters, respectively (Tab 9).

Table 8 Statistical results of MRSA in the DRASTIC index

The sensitivity of variability index (S) (%)				Removed parameters
SD	Min.	Max.	Ave.	
0.414	0.05	2.36	1.36	D
0.775	0.07	3.06	1.48	R
0.311	0.05	1.31	0.44	A
0.486	0.00	1.65	0.73	S
0.339	0.03	1.31	0.51	T
0.894	0.25	3.84	1.88	I
0.550	0.03	1.98	1.25	C

Table 9 Statistical results of SPSA in the DRASTIC index

Effective weight (%)				Theoretical weight (%)	Theoretical weight	Parameters
SD	Min.	Max.	Ave.			
6.179	3.23	28.46	8.33	21.74	5	D
11.998	14.06	73.47	43.26	17.4	4	R
3.190	7.26	22.13	14.91	13.04	3	A
2.916	4.49	14.29	9. 89	8.7	2	S
2.222	6.45	14.71	11.35	4.3	1	T
5.367	15.79	37.31	25.55	21.74	5	I
3.738	2.42	18.75	7.01	13.04	3	C

3.4. The sensibility of the CDRASTIC index

The MRSA in the CDRASTIC index is performed by eliminating on data layer at a time as indicated in Tab 10. The mean variation index of hydraulic conductivity parameter is 4.13%. The hydraulic conductivity has a greater effect on the aquifer vulnerability followed by water table depth (4.05%), soil media (3.82%), topography (3.68%), aquifer media (3.28%), net recharge (2.72%), the impact of the vadose zone (2.33%), and land use (1.99%).

The effective weight derived from the SPSA to the CDRASTIC index is shown in Tab 11. The average value of the effective weight of the net recharge factor is 32.62%. This shows that this factor is more effective in vulnerability assessment using CDRASTIC index. The hydraulic conductivity displays the lowest effective weights (5.32%). The topography, net recharge, and land use had upper effective weights toward the theoretical weights specified by CDRASTIC index. The average value of the effective weight of the land use parameter is 24.82%. This shows that this parameter is the second effective parameter in aquifer vulnerability, using the CDRASTIC index (Tab 11).

Table 10 Statistical results of MRSA in the CDRASTIC index

The sensitivity of variability index (S) (%)				Removed parameters
SD	Min.	Max.	Ave.	
1.403	0.50	6.48	4.05	D
1.617	0.11	10.91	2.72	R
1.541	0.06	5.99	3.28	A
1.508	0.67	6.60	3.82	S
1.353	0.87	5.87	3.68	T
1.439	0.06	5.12	2.33	I
1.480	0.55	6.72	4.13	C
0.375	1.23	3.00	1.99	L

Table 11 Statistical results of SPSA in the CDRASTIC index

Effective weight (%)				Theoretical weight (%)	Theoretical weight	Parameters
SD	Min.	Max.	Ave.			
4.849	2.63	26.88	6.27	21.74	5	D
10.672	10.4	66.67	32.62	17.4	4	R
3.026	6.29	20.00	11.23	13.04	3	A
2.621	3.31	12.96	7.5	8.7	2	S
1.609	5.2	12.82	8.45	4.3	1	T
4.648	10.87	32.05	19.2	21.74	5	I
3.134	2.1	14. 88	5.32	13.04	3	C
10.122	3.88	42.37	24.82	17.85	5	L

4. Conclusions

Evaluations of vulnerability indexes for the Kerman–Baghin aquifer were conducted using the GIS-based DRASTIC and CDRASTIC indexes. Seven hydro–geological factors (the letters comprising the acronym) are applied to determine aquifer vulnerability with DRASTIC; eight hydro–geological parameters (one additional to the seven in DRASTIC) with the CDRASTIC index. From the DRASTIC index values, it was determined that 10.4% of the aquifer is under high (8.46%) and very high (1.94%) vulnerability. From the CDRASTIC index values, it was determined that 8.75% of the aquifer is under high (6.28%) and very high (2.47%) vulnerability. Also, we found that parts of the north, south, southeast, and northwest are under low and very low vulnerability using the DRASTIC and CDRASTIC indexes. Agricultural and industrial activities are found to be a major threat in the zones with high and very high vulnerability. The MRSA signifies the fact that hydraulic conductivity and the impact of the vadose zone factors induce a high risk of aquifer contamination according to the DRASTIC and CDRASTIC indexes, respectively. In both indexes, the SPSA analysis shows the net recharge factor as a high risk for aquifer contamination. These results indicate that the studied indexes are effective tools for determining groundwater vulnerability. Also, these results could be utilized by private and government agencies as a guide for groundwater contamination assessment in Iran.

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Competing interests. The authors declare that they have no conflict of interest.

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No.2 Reviewer Comments and Authors Responses

I am very much thankful to the reviewer for his/her deep and thorough review. I have revised my present research paper in the light of his/her useful suggestions and comments. I hope my revision has improved the paper to a level of his/her satisfaction. Number wise answers to his/her specific comments/suggestions/queries are as follows:

Comment-1: The title should be modified. In fact, this is only a case study not a general evaluation of existing methods or a sensitivity test approach. To me, what the authors did is a characterization of a specific Iranian aquifer. This should be made clear in the title, rather than to generalize the results. In any case, the authors should not claim their study may quantify the contribution of 'sensitivity analysis' in groundwater vulnerability assessment. This is too broad but not what the authors actually achieved.

Response: Manuscript title changed**.** The changes highlighted in the manuscript with the yellow color.

Comment-2: The authors should highlight their contributions in Abstract and Conclusion sections. Again, the contributions should be specific, not generally saying the sensitivity test is useful.

Response: The required changes were made. The changes highlighted in the manuscript with the yellow color.

Comment-3: Introduction. This part should be modified further. Apart from the English, the literature review on DRASTIC should be developed further. In the present manuscript, the authors only listed a few studies that apply the methods. They did not discuss the significance or the limitations of the approach. Also, the purpose of the research is introduced in a not very convincing way. Why the droughts and pumpings make the studies on pathology and groundwater contamination undeniable?

Response: The required changes were made. The significance or the limitations of the approach .were added The purpose of the research was revised. Due to recent droughts, this aquifer has been under heavy pumping stress to irrigate crops, which caused a graduated drop of water level. Consequently, this could increase contamination potential in the aquifer. The changes highlighted in the manuscript with the yellow color.

Comment-4: Methodology. The authors mixed the presentation of methods and data. This section should be called Methods and Materials (or Datasets). The authors should give support for the selected values for each parameter listed in all the Tables. How do you assign weights to each factor? Based on which data or information? Are these subjectively assigned or you have references?

Response: The required changes were made. The name of this section was changed . According to Aller et al.1985, weight factors are a constant value in all studies. But the ranges vary according to the type or amount of factors in each geographic area. Based on the degree of their impact on pollution, assigned a rank of between 1 to 10. Relevant reference was added. Of course, assigning rankings to each of ranges is based on an inherent mentality that can be one of the limitations of overlapping methods. As we mentioned in the introduction section. The changes highlighted in the manuscript with the yellow color.

Comment-5: Is it really useful to separate the components and discuss about their general functions? Consider to merge sections 2.3 to 2.10. These small sections make the presentation fragmented.

Response: The required changes were made. The changes highlighted in the manuscript with the yellow color.

Comment-6: Conclusions. Here the authors mentioned agricultural and industrial activities. However, these are not discussed in the main body of the Results section. How do you support your conclusion? I suggest the authors to make specific conclusions that are directly derived from study. To discuss about general concept based on this single characterization case study and sensitivity test makes no sense.

Response: The conclusion section was rewritten. The changes highlighted in the manuscript with the yellow color.

Comment: I marked a number of comments on English usage directly on the PDF file while I went through the manuscript (see the attached supplement file). I used the PDF file after the author's correction based on the comments from Reviewer #1. I want to point out that my corrections are not exhaustive. The authors should ask a native speaker to help to improve the English. Otherwise, it is too hard to comprehend the study as it is.

Response: Your valuable comments applied to the manuscript (in the supplement file). The manuscript was also edited by a native English editor.

Changes made based on NO.2 referee comments are highlighted in the rewritten manuscript as follows:

GIS-Based DRASTIC and Composite DRASTIC Indexes for Assessment Groundwater Vulnerability in Baghin Aquifer, Kerman, Iran

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ABSTRACT

The present study estimated the Kerman–Baghin aquifer vulnerability using DRASTIC and composite DRASTIC (CDRASTIC) indexes. Factors affecting the transfer of contamination, including water table depth, soil media, aquifer media, impact of vadose zone, topography, hydraulic conductivity, and land use, were ranked, weighted, and integrated, using a geographical information system (GIS). A sensitivity test was also performed to determine parameters sensitivity. Results showed that the topographic layer displays a gentle slope in the aquifer. Most of the aquifer was covered with irrigated field crops and grassland with a moderate vegetation cover. In addition, the aquifer vulnerability maps indicated very similar results, recognizing the northwest parts of the aquifer as areas with high to very high vulnerability. The map removal sensibility analysis (MRSA) reveal that the impact of vadose zone (in the DRASTIC index) and hydraulic conductivity (in the CDRASTIC index) as the most important parameters in the vulnerability evaluation. In both indexes, the single-parameter sensibility analysis (SPSA) showed net recharge as the most effective factor in the vulnerability estimation. From this study, it could be concluded that vulnerability maps could be used as a tool to control human activities for protection and sustainable usage.

Keywords: Vulnerability; Sensitivity Analyses; DRASTIC; Composite DRASTIC; Kerman–Baghin Aquifer

1. Introduction

Groundwater is a significant and principal freshwater resource in most parts of the world, especially for arid and semi-arid areas. Water quality has been emphasized more in groundwater management (Neshat et al., 2014; Manap et al., 2013; Manap et al., 2014a; Ayazi et al., 2010). The potential groundwater contamination by human activities at or near the surface of groundwater has been considered the major base to manage this resource by implementing preventative policies (Tilahun and Merkel, 2010).

Groundwater vulnerability is a measure of how easy or how hard it is for pollution or contamination at the land surface to reach a production aquifer. In other words, it is a measure of the "degree of insulation" that natural and manmade factors provide to keep pollution away from groundwater (Sarah and Patricia, 1993; Neshat et al., 2014). Vulnerability maps are commonly performed at the sub-region and regional scales. Normally, they are not applied to site-specific evaluations, including zones smaller than a few tens of square kilometers (Baalousha, 2006; Tilahun and Merkel, 2010). Various techniques have been developed to assess groundwater susceptibility with great precision (Javadi et al., 2010; Javadi et al., 2011). Most of the methods are based on analytic tools to associate groundwater contamination to land operations. There are three types of evaluation methods: the process-based simulations, the statistic procedures and, and the overlay and index approaches (Neshat et al., 2014; Dixon, 2004).

Process-based approach involves numerical modeling and is useful at the local but not the regional level. Statistical approach involves correlating actual water quality data to spatial variables and requires a large amount of site specific data (National Research Council, 1993). Overlay and index procedures affirm the incorporation of various zonal maps by allocating a numeral index. Both procedures are simple to use in the geographic information system, especially on a zonal measure. Hence, these methods are the most popular procedures applied to vulnerability estimation (Neshat et al., 2014). The overlay and index methods have some significant advantages; firstly, they have become popular because the methodology is fairly straightforward that can be easily implemented with any GIS application software. The concept of overlaying data layers is easily comprehended even by less experienced users. In addition, the data requirement could be considered as moderate, since nowadays most data come in digital format. Hydrogeological information is either available or could be estimated using relevant data. Consequently, these methods give relatively accurate results for extensive areas with a complex geological structure. Lastly, the product of this approach could be easily interpreted by water-resource managers and could be incorporated into decision-making processes. Even a simple visual inspection of the vulnerability map can reveal important contamination hotspots. Probably the most important and obvious disadvantage of these methods raised by scientists and experts is the inherent subjectivity in the determination of the rating scales and the weighting coefficients (National Research Council, 1993).

The most extensively used methods for the groundwater vulnerability evaluation are GODS (Ghazavi and Ebrahimi, 2015), IRISH (Daly and Drew, 1999), AVI (Raju et al., 2014), and DRASTIC (Neshat et al., 2014; Baghapour et al., 2014; Baghapour et al., 2016).

The DRASTIC index, proposed by Aller et al (1985), is considered as one of the best indexes for groundwater vulnerability estimation. This method ignores the influence of zonal properties. Thus, identical weights and rating values are utilized. In addition, this technique fails to apply a standard validation test for the aquifer. Therefore, several investigators developed this index using various techniques (Neshat et al., 2014). The higher DRASTIC index represents the greater contamination potential and inversely. After calculating the DRASTIC index, it should be possible to identify the zones that are more prone to pollution. This index only provides a relative estimation and is not created to make a complete assessment (Baalousha, 2006).

Many studies have been conducted using DRASTIC index to estimate the groundwater vulnerability in different regions of the world (Jaseela et al., 2016; Zghibi et al., 2016; Kardan Moghaddam et al., 2017; Kumar et al., 2016; Neshat and Pradhan, 2017; Souleymane and Tang, 2017; Ghosh and Kanchan, 2016; Saida et al., 2017); however, there are still a number of studies that used the CDRASTIC index for groundwater vulnerability evaluation (Baghapour et al., 2016; Baghapour et al., 2014; Secunda et al., 1998; Jayasekera et al., 2011; Shirazi et al., 2012; Jayasekera et al., 2008). Boughriba et al. (2010) utilized DRASTIC index in geographical information system environment to estimate the aquifer vulnerability. They provided the DRASTIC modified map prepared from total DRASTIC indexes and small monitoring network maps including high and medium classes. Then, authors integrated the map with land use map to provide the contamination potential map. They reported the new obtained groundwater vulnerability map, including three various classes, namely very high, high, and medium. Babiker et al. (2005) used the DRASTIC index to determine point's prone to contamination from human activities in the aquifer. They reported that the western and eastern parts of the aquifer fall in the high and medium classes, respectively in terms of vulnerability. The final aquifer vulnerability map represented that the high risk of pollution is in the eastern part of aquifer due to agriculture activities. They also observed that net recharge inflicts the largest impact on the aquifer vulnerability, followed by soil media, topography, the impact of vadose zone, and hydraulic conductivity.

The average annual precipitation in Iran is 257 mm (namely less than one-third of the average annual precipitation at the global level). Water scarcity is a very critical and serious problem in Iran (Chitsazan and Akhtari, 2006; Modabberi et al., 2017). In addition, the groundwater reduction makes the problem even worse. Groundwater is the only freshwater resource in the Kerman province, due to the lack of surface water. The Baghin aquifer is located in the central part of Kerman province of Iran. Due to recent droughts, this aquifer has been under heavy pumping stress to irrigate crops, which caused a graduated drop of water level. Consequently, this could increase contamination potential in the aquifer. Therefore, the aim of this research was to provide a vulnerability map for the Kerman–Baghin aquifer and performing a sensitivity analysis to identify the most influential factors in vulnerability assessment.

2. Methods and Materials

2.1. Study Area

Kerman Province covers both arid and semi-arid lands. The present study included a 2023 km2 area (29◦ 47′ to 30◦ 31′ N latitude and 56◦ 18′ to 57◦ 37′ E longitude) located in the central part of Kerman Province, Iran (Figure 1). The study area is mostly covered with agricultural lands (Neshat et al., 2014). The mean annual rainfall is 108.3 mm (during 2017) in the study area; the highest and lowest topographic elevation is 1,980 and 1,633 m above sea level; and eventually, the mean, minimum, and maximum annual temperatures are 17◦C, -12◦C, and 41◦C, respectively (during 2017).

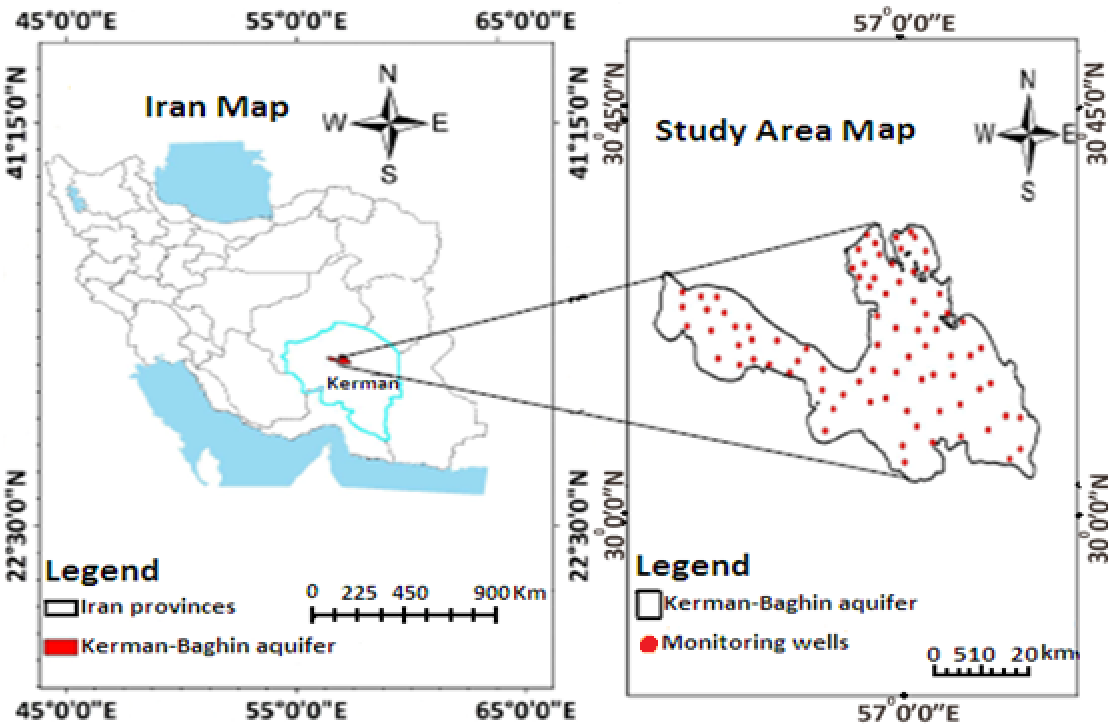

Figure 1. Location map of the Kerman–Baghin aquifer

2.2. DRASTIC and CDRASTIC Indexes Computation

DRASTIC is a procedure developed by the United States Environmental Protection Agency (U.S EPA) to evaluate the groundwater pollution (Aller et al., 1985). The DRASTIC index is obtained using the following relation (Kardan Moghaddam et al., 2017; Neshat and Pradhan, 2017):

$$\text{DRASTIC index} = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w, \quad (1)$$

where DRASTIC comprises the effective factors in the DRASTIC index. D, R, A, S, T, I, and C stand for water table depth, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity, respectively. In addition, "*r*" and "*w*" are the rating and weight of each factor, respectively. The ratings and weights of factors are presented in Table 1. A high DRASTIC index corresponds to a high vulnerability of the aquifer to pollution. In the DRASTIC index, each parameter is rated on a scale from 1 to 10 that shows the relative contamination potential of that parameter for that area. In addition, in the DRASTIC index, one weight (1 to 5) is assigned to each of the parameters. Weight values show the relative significance of the parameters with respect to each other. Ranges of vulnerability corresponding to the DRASTIC index are presented in Table 2.

Table 1 Rating and weight related to DRASTIC index factors (Aller et al., 1985)

DRASTIC parameters	Range	Rating (r)	Weight (w)
Water table depth (m)	0.0-1.5	10	
	1.5-4.6	9	
	4.6-9.1	7	
	9.1-15.2	5	5
	15.2-22.9	3	
	22.9-30.5	2	
	>30.5	1	
Net recharge	11-13	10	
	9-11	8	
	7-9	5	4
	5-7	3	
	3-5	1	
Aquifer media	Rubble and sand	9	
	Gravel and sand	7	
	Gravel, sand, clay, and silt	5	3
	Sand and clay	4	
	Sand, clay, and silt	3	
Soil media	Rubble, sand, clay, and silt	9	
	Gravel and sand	7	
	Gravel, sand, clay, and silt	6	
	Sand	5	2
	Sand, clay, and silt	3	
	clay and silt	2	
Topography or slope (%)	0-2	10	
	2-6	9	
	6-12	5	1
	12-18	3	
	>18	1	

The impact of the vadose zone	Rubble, sand, clay, and silt	9	
	Gravel and sand	7	
	Gravel, sand, clay, and silt	5	5
	Sand, clay, and silt	3	
Hydraulic conductivity (m/day)	0-4.1	1	
	4.1-12.2	2	3
	12.2-28.5	4	
	28.5-40.7	6	
	40.7-81.5	8	

Table 2 Range of vulnerability related to the DRASTIC index

Vulnerability	Ranges
Very low	23-46
Low	47-92
Moderate	93-136
High	137-184
Very high	>185

To obtain the CDRASTIC index, an additional factor (land use) is added to the above relation. Thus, the CDRASTIC index was obtained as follows:

$$\text{CDRASTIC index} = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w + L_r L_w, \quad (2)$$

where L_w and L_r are the relative weight and rating related to land use, respectively. Ratings and weightings applied to the pollution potential are shown in Table 3 which are related to land use based on the CDRASTIC index. The final outputs of CDRASTIC relation range from 28 to 280.Vulnerability ranges based on the CDRASTIC index are presented in Table 4.

Table 3 Ratings and weighting applied to pollution potential related to land use based on CDRASTIC index (Aller et al., 1985)

Land use	Rating	Weight
Irrigated field crops + Urban areas	10	
Irrigated field crops + Grassland with poor vegetation cover + Urban areas	9	
Irrigated field crops + Grassland with moderate vegetation cover + Urban areas	8	
Irrigated field crops	8	
Irrigated field crops + Fallow land + Grassland with poor vegetation cover	7	

Irrigated field crops + Grassland with poor vegetation cover	7	
Irrigated field crops + Grassland with moderate vegetation cover	6	
Irrigated field crops + Rocky + Urban areas	5	5
Irrigated field crops + Grassland with poor vegetation cover + Woodland	5	
Irrigated field crops + Woodland	5	
Irrigated field crops + Rocky	4	
Fallow land	3	
Fallow land + Grassland with poor vegetation cover	3	
Fallow land + Grassland with moderate vegetation cover	3	
Grassland with poor vegetation cover	2	
Grassland with moderate vegetation cover	2	
Grassland with moderate vegetation cover + Woodland	1	
Sand dune +Grassland with moderate vegetation cover	1	
Sand dune	1	

Table 4 Vulnerability ranges related to CDRASTIC index

Vulnerability	Ranges
Very low	<100
Low	100-145
Moderate	145-190
High	190-235
Very high	≥235

2.3. Factors Affecting Transfer of Contamination

Water table depth is the distance of water table from ground surface in a well (Baghapour et al., 2016). Eighty-three wells were utilized in the Kerman–Baghin aquifer to obtain this factor. The interpolation procedure was used to provide a raster map of the water table depth, which was categorized based on Table 2.

Net recharge is the amount of runoff that penetrated into the ground and reaches the groundwater surface (Singh et al., 2015; Ghosh and Kanchan, 2016). This research used the Piscopo method (Chitsazan and Akhtari, 2009) to provide net recharge layer for the Kerman–Baghin aquifer according to the following equation and Table 5:

$$\text{Net recharge slope } (\%) + \text{ rainfall} + \text{soil permeability.} \quad (3)$$

In the above equation, the percentage of slope was calculated from a topographical map, using a digital elevation model. In addition, a soil permeability map was created using the Kerman–Baghin aquifer soil map (with scale 1:250000) and the drilling logs of 83 wells. In the end, a map of rainfall rate in the area was compiled based on annual average precipitation. Ratings and weights of net recharge are presented in Table 5.

Table 5 Weight, rating, and range of net recharge (Aller et al., 1985)

Slope (%)		**Rainfall**		**Soil permeability**		**Net Recharge**		
Range (%)	**Factor**	Range (mm/year)	**Factor**	Range	**Facto r**	Range (cm/year)	**Ratin g**	**Weigh t**
<2	4	>850	4	High	5	11-13	10	
2-10	3	700-850	3	Moderate to high	4	9-11	8	
10-33	2	500-700	2	Moderate	3	7-9	5	4
>33	1	<500	1	Low	2	5-7	3	
				Very low	1	3-5	1	

Aquifer media controls the movement of groundwater streams in the aquifer (Aller et al., 1985; Singh et al., 2015). To obtain this layer, drilling log data of 83 wells were used. Data were collected from Kerman Regional Water Office (KRWO). The range of the aquifer media layer is shown in Table 2.

Soil media has a considerable impact on the amount of water surface that can penetrate into the aquifer. Therefore, where the soil layer is thick, the debilitation processes such as absorption, filtration, degradation, and evaporation may be considerable (Singh et al., 2015). A soil media raster map was provided using the Kerman–Baghin aquifer soil map and the wells drilling logs. The range of the soil media layer is presented in Table 2.

Topography controls the residence time of water inside on the soil and the degree of penetration (Singh et al., 2015). To obtain this layer, the percentage of the slope was provided from the topographical map, using a digital elevation model. Data were collected from the KRWO. The range of the topographic layer is presented in Table 2.

Vadose zone is the unsaturated area located between the topographic surface and the groundwater level (Singh et al., 2015). It plays a significant role in decreasing groundwater contamination by pollutant debilitation processes such as purification, chemical reaction, and dispersal (Shirazi et al., 2012). This study used the lithologic data of 83 observation and exploration wells to design the impact of vadose zone raster map of aquifer. Data were collected from the KRWO. The range of the impact of vadose zone layer is depicted in Table 2.

Hydraulic conductivity refers to the capability of the aquifer to transfer water. High hydraulic conductivity areas demonstrate a high potential for groundwater contamination (Singh et al., 2015; Aller et al., 1985). To prepare this layer, data derived from pumping tests of wells were used. The range of hydraulic conductivity layer is shown in Table 2.

Land use influences groundwater resources via variation in recharge amount and by changing freshwater demands for water. Land use is obligatory since it is required by the CDRASTIC index. The Indian remote sensing satellite information was utilized to provide land use raster map. The weight and rating related to land use layer are presented in Table 3.

2.4. Sensitivity Analyses

One of the main advantages of the DRASTIC index is the evaluation performance because, a high number of input data are used, and this allows to restrict the effects of errors on final results. Nevertheless, some authors, namely Babikeret al. (2005), Barber et al.(1993), and Merchant (1994), reported that similar results could be obtained using fewer data and at lower costs. The unavoidable subjectivity related to the choosing seven factors, ranks, and weights used to calculate the vulnerability index has also been criticized. Therefore, in order to eliminate the aforementioned criticisms, two sensitivity analyses were performed as follows (Napolitano and Fabbri, 1996):

A. Map Removal Sensibility Analysis (MRSA)

MRSA value indicates the vulnerability map sensibility to removal of one or more maps from the suitability analysis. MRSA is calculated as follows (Babiker et al., 2005; Martínez-Bastida et al., 2010; Saidi et al., 2011; Modabberi et al., 2017):

$$S = \left[\left|\frac{\frac{V}{N} - \frac{V'}{n}}{V}\right|\right] \times 100, \qquad (4)$$

where S stands for the sensibility value expressed in terms of variation index, V is the intrinsic vulnerability index (real vulnerability index) and V′ is the intrinsic vulnerability index after removing X; N and n are the number of data used to calculate V and V′, respectively (Babiker et al., 2005; Martínez-Bastida et al., 2010; Saidi et al., 2011; Modabberi et al., 2017).

B. Single-Parameter Sensibility Analysis (SPSA)

SPSA was first introduced by Napolitano and Fabbri (1996). This test shows the effect of each DRASTIC factor on the final vulnerability index. Using this test derived from Equation 5, the real and effective weight of each factor, compared to the theoretical weight assigned by the analytical model was calculated by Babiker et al(2005), Martínez-Bastida et al (2010), Saidi et al(2011) and Modabberi et al (2017);

$$W = \left[\frac{P_r P_w}{V}\right] \times 100, \qquad (5)$$

where W is the effective weight of each factor. P_r and P_w are the rank and weight assigned to P, respectively. V is the intrinsic vulnerability index (Martínez-Bastida et al., 2010; Babiker et al., 2005; Saidi et al., 2011; Modabberi et al., 2017).

3. Results and Discussion

3.1. DRASTIC and CDRASTIC Parameters

Based on data shown in Table 2, the assigned rating of water table depth varies from 1 to 10. In addition, based on the results presented in Table 6, water table depth in the aquifer varies from 4.6 to >30.5 m (rating 1 to 7). About 27.55% of the aquifer has a depth greater than 30.5 m, and 66.16 % of the aquifer has a depth ranging from 9.1 m and 30.5 m. Less than 7% of the aquifer has a depth between 4.6 m and 9.1 m. The Kerman–Baghin aquifer rated map of water table depth is presented in Figure 2(A). According to Figure 2(A) and Table 6, the minimum impact of water table depth on aquifer vulnerability occurs in the central parts (6.39%), whereas the maximum impact occurs in the north, south, northwest, and southeast parts (27.55%).

According to the results presented in Table 6, 75.81% of the aquifer has a net recharge value from 7 to 9 cm/year. Anet recharge value between 9 and 11 cm/year was found for 11.74% of the aquifer. The Kerman–Baghin aquifer rated map of net recharge is shown in Figure 2(B). According to Piscopo's method, the Kerman–Baghin aquifer was divided into three classes, with regard to net recharge. The highest net recharge value was observed in the north, northeast, south, southwest, parts of the northwest, parts of the center, and parts of the southeast (75.81%), whereas the least net recharge value appeared in parts of the northwest and center (11.74%), as shown in Figure 2(B) and Table 6.

As observed in Table 6, the majority of the Kerman–Baghin aquifer media is composed of sand, clay, and silt (75.21%). The Kerman–Baghin aquifer rated map of aquifer media is presented in Figure 3(A). Parts of the aquifer in the north, northwest, northeast, center, and southeast are composed of sand, clay, and silt. Parts of the aquifer in the northwest are composed of rubble and sand (5.58%). Parts of the aquifer in the south and northwest are composed of gravel and sand (8.95%), and gravel, sand, clay, and silt (10.26%).

The Kerman–Baghin aquifer rated map of soil media is presented in Figure 3(B). The soil map depicts six different soil classes. The highest rank (rank = 9) was assigned to rubble, sand, clay, and silt (a combination of rubble, sand, clay and silt soils). In addition, the lowest rank (rank = 2) was assigned to clay and silt(a combination of clay and silt soils). Most of the aquifer soil media is covered with silt, sand, and clay (about 80%).

The Kerman–Baghin aquifer rated map of topography is shown in Figure 4(A). The topographical layer shows a gentle slope (0 to 6%) over most of the aquifer, hence gaining ranks of 9 and 10. A slope range of 0 to 2% includes 34.72% of the study area, and its rating (slope range = 0–2%) is 10. In addition, 65.28% of the aquifer has a slope range of 2 to 6% (parts of the northwest) as shown in Figure 4(A) and Table 6. As the gradient increases, the runoff increases as well (Israil et al., 2006) leading to less penetration (Jaiswal et al., 2003). According to Madrucci et al. (2008), the gradients higher than 35° are considered restrictions on groundwater desirability because of the lack of springs.

The Kerman–Baghin aquifer rated map of the impact of vadose zone is indicated in Figure 4(B). According to the results, the soil with a rank of 5 (gravel, sand, clay, and silt) is more effective in aquifer vulnerability (35.47%). Other various types of soils such as sand, clay, and silt (parts of the north, northeast, south, and southeast), gravel and sand (parts of the center and northwest), and rubble, sand, clay, and silt (parts of the northwest) cover 34.24%, 20.39%, and 9.9% of the aquifer, respectively, as shown in Figure 4(B) and Table 6. Sandy soil is effective on groundwater occurrence because of the high rate of penetration (Srivastava and Bhattacharya, 2006). However, clay soil is arranged poorly because of low infiltration (Manap et al., 2014b).

The Kerman–Baghin aquifer rated map of hydraulic conductivity is presented in Figure 5(A). Hydraulic conductivity shows high variability. Our study results show that hydraulic conductivity of the Kerman–Baghin aquifer varied from 0 to 81.5 m/day. The potential for groundwater contamination was greater in zones with high hydraulic conductivity (38.27%). As shown in Figure 5(A) and Table 6, 29.51%, 23.93%, 5.98%, and 2.31% of the study areas have hydraulic conductivity in the ranges of 0 to 4.1 m/day, 12.2 to 28.5 m/day, 28.5 to 40.7 m/day, and 40.7 to 81.5 m/day, respectively.

The Kerman–Baghin aquifer rated map of land use is presented in Figure 5(B). Our results show that the majority of the Kerman–Baghin aquifer is covered with irrigated field crops and grassland with moderate vegetation cover (20.45%). Less than 4% of the study area is irrigated field crops and urban areas (3.61%), and 58.47% of the study area is irrigated field crops with urban areas, grassland with poor and moderate vegetation cover, fallow land, woodland, and rocky ground. In addition, 10.17% of the study area is fallow land with poor grassland and moderate vegetation, and 13.72% of the study area is sand dunes with poor grassland and moderate vegetation cover and woodland as shown in Figure 5(B) and Tables 3 and 6.

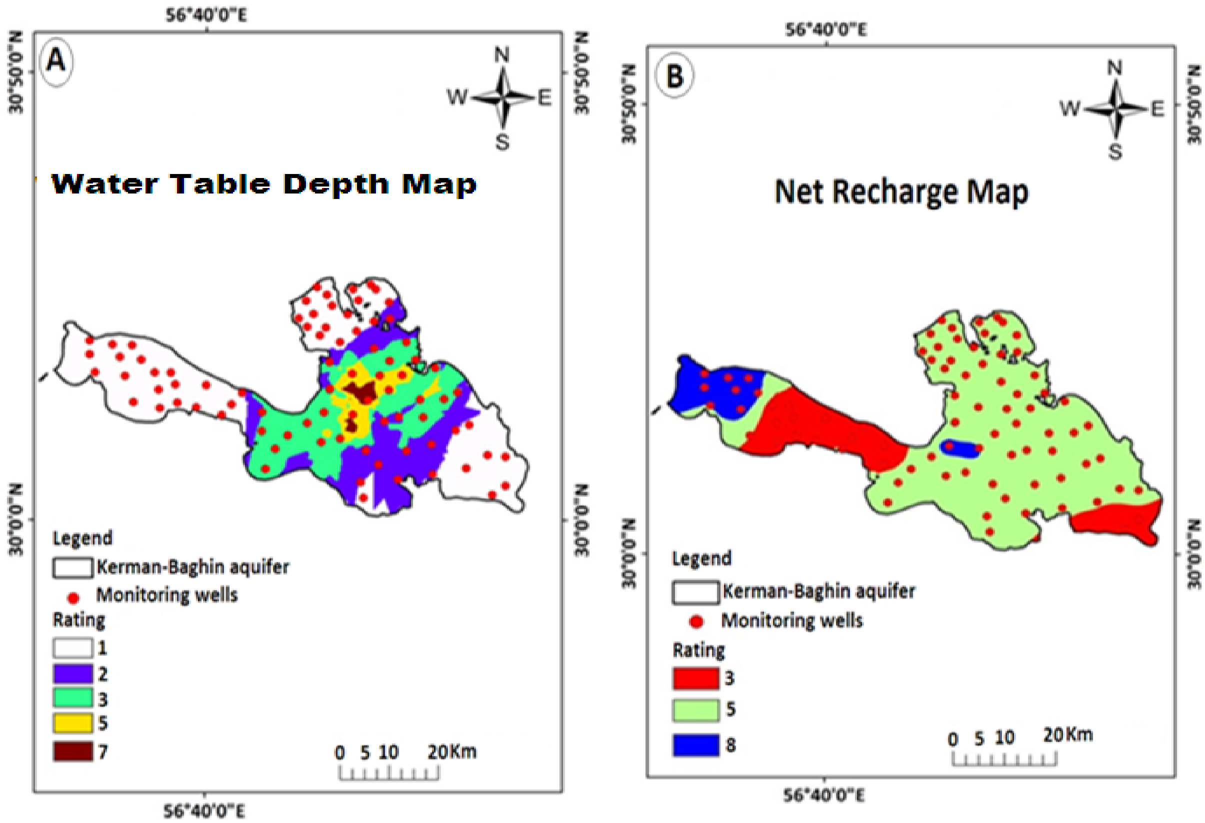

Figure 2. Kerman–Baghin aquifer rated maps of A) water table depth and B) net recharge

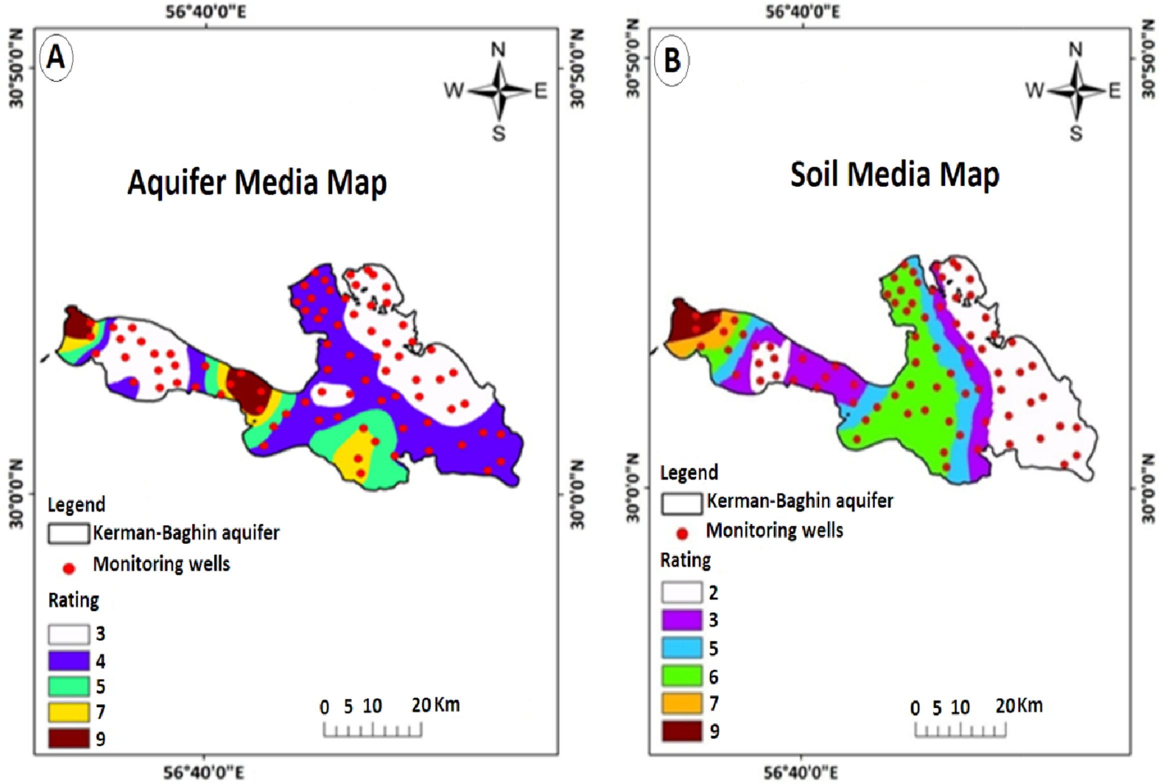

Figure 3. Kerman–Baghin aquifer rated maps of A) aquifer media and B) soil media

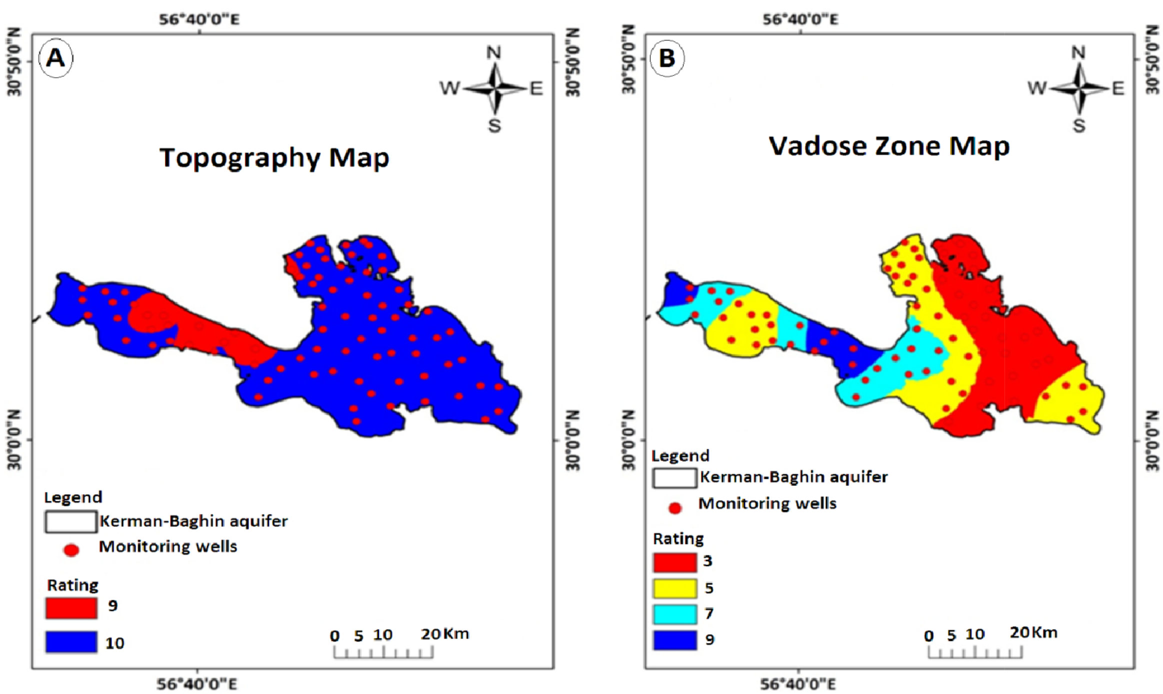

Figure. 4. Kerman–Baghin aquifer rated maps of A) topography and B) vadose zone

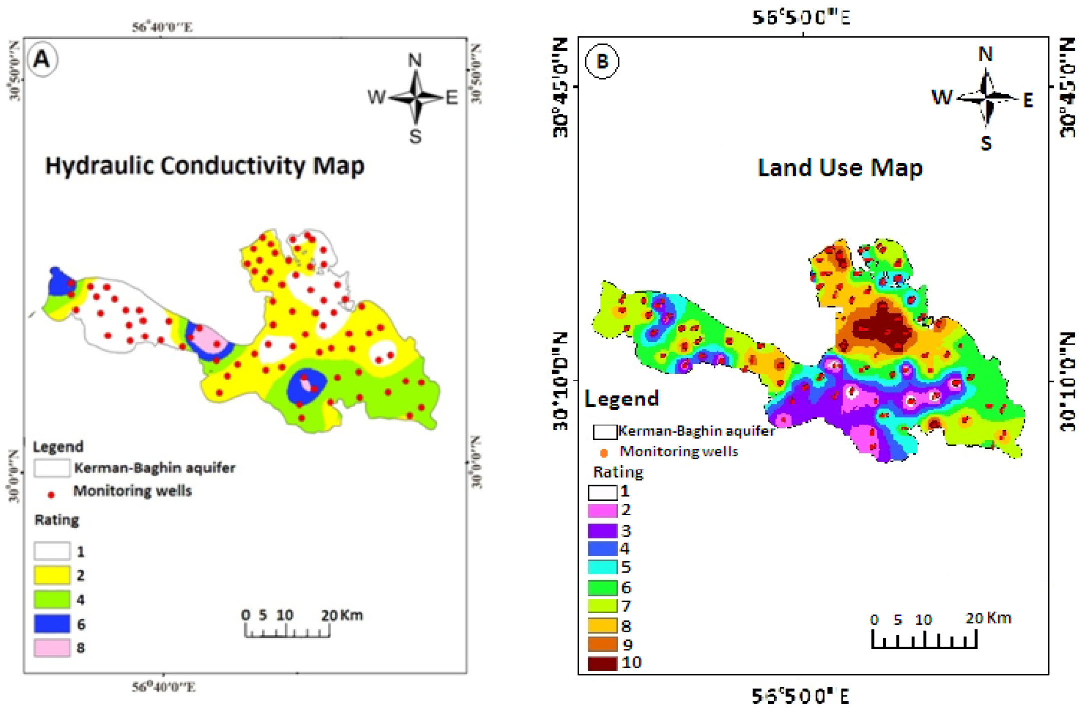

Figure. 5. Kerman–Baghin aquifer rated maps of A) hydraulic conductivity and B) land use

Table 6 Area of rating (km2 and %) of DRASTIC and CDRASTIC parameters

DRASTIC and CDRASTIC indexes parameters	Rating	Area (km^2)	Area (%)	The aquifer geographic directions covered by the respective rating in the parameters rated maps
Water table depth	1	557.73	27.55	Parts of the north, south, northwest, and southeast
	2	472.18	23.34	Parts of the north, south, and center
	3	469.78	23.29	Parts of the center
	5	395.00	19.53	Parts of the center
	7	129.14	6.39	Parts of the center
Net recharge	3	252.04	12.45	Parts of southeast, and northwest
	5	1534.15	75.81	North, northeast, south, southwest, and parts of the northwest, center, southeast
	8	237.6	11.74	Parts of the northwest and center
Aquifer media	3	743.18	36.72	Parts of the north, northwest, northeast, and center
	4	779.01	38.49	Parts of the north, northwest, southeast, and center
	5	207.81	10.26	Parts of the south, and northwest
	7	181.02	8.95	Parts of the south, and northwest
	9	112.76	5.58	Parts of the northwest
Soil media	2	658.5	32.53	Parts of the north, northwest, northeast, and southeast
	3	399.72	19.75	Parts of the north, northwest, south, and center

	5	297.44	14.69	Parts of the north, northwest, south, and center
	6	538.77	26.62	Parts of the northwest, center, and southwest
	7	67.56	3.33	Parts of the northwest
	9	61.79	3.08	Parts of the northwest
Topography	9	702.74	34.72	North, northwest, northeast, south, southeast, southwest, and center
	10	1321.07	65.28	parts of the northwest
The impact of the vadose zone	3	692.87	34.24	Parts of the north, northeast, south, and southeast
	5	717.91	35.47	Parts of the north, northwest, south, southeast, and center
	7	412.49	20.39	Parts of the center, and northwest
	9	200.53	9.9	Parts of the northwest
Hydraulic conductivity	1	597.11	29.51	Parts of the northeast, northwest, southeast, and center
	2	774.52	38.27	parts of the northwest, south, southeast, and center
	4	484.17	23.93	Parts of the northwest, south, and southeast
	6	120.99	5.98	Parts of the south, and northwest
	8	46.7	2.31	Parts of the south, and northwest
Land use	1	112.48	5.56	Parts of the south
	2	165.02	8.16	Parts of the south
	3	205.65	10.17	Parts of the south, and center
	4	357.06	17.64	Parts of the south, southwest, northwest, and center
	5	234.86	11.61	Parts of the southeast, northwest, and center
	6	413.86	20.45	Parts of the southeast, northwest, northeast, and center
	7	182.63	9.02	Parts of the north, northwest, and northeast
	8	169.4	8.37	Parts of the north, northwest, and northeast
	9	109.42	5.41	Parts of the north, northwest, and northeast
	10	73.09	3.61	Parts of the north

3.2. DRASTIC and CDRASTIC Vulnerability Indexes

The Kerman–Baghin aquifer vulnerability map obtained using DRASTIC and CDRASTIC indexes is shown in Figure 6. In the studied aquifer, the vulnerability falls under very high, high, moderate, low, and very low vulnerable areas. It is found that in both indexes, the north, northeast, northwest, south, southwest, southeast and center parts come under low and very low vulnerability. This could be attributed to low water depth, hydraulic conductivity, and net recharge characterizing these aquifer areas; another reason might be that the aquifer media is mostly clay, sand and silt soils. The vulnerability area, identified by investigated indexes, is illustrated in Table 7. Low and very low vulnerable zones cover 25.21% and 38.31%of the Kerman–Baghin aquifer respectively using DRASTIC index. Very low and low vulnerable zones cover 24.95% and 40.41%, respectively, using the CDRASTIC index. This is primarily due to water table depth and relatively low permeability of vadose zone in such aquifers (Colins et al., 2016).About 26% of the studied aquifer had moderate groundwater pollution potential, using DRASTIC and CDRASTIC indexes. This does not mean that such areas are without pollution; rather, they are relatively prone to pollution when compared to other areas (Colins et al., 2016). From the DRASTIC index values, it was found that 10.4% of the study aquifer was under high (8.46%) and very high (1.94%) vulnerability. The results of the study showed that 8.75% of the aquifer is in the ranges of 190 to 235 and greater than 235 in the CDRASTIC index (Table 7). According to these two indexes, the vulnerability maps indicated very same findings, showing the northwest portion of the aquifer as high and very high vulnerable zones. The high vulnerability can be attributed to great water depth, hydraulic conductivity, and net recharge in these aquifer areas. In addition, this can due to the great slope in this area.

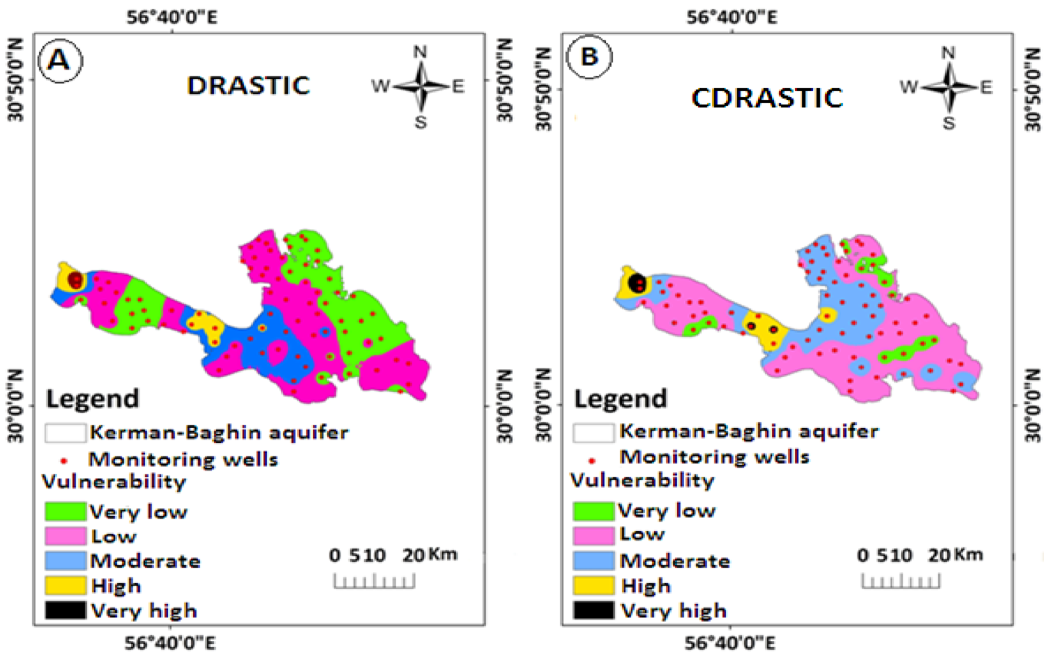

Figure 6. Vulnerability maps of Kerman–Baghin aquifer by DRASTIC and CDRASTIC indexes

Table 7 Area of vulnerability (km2 and %) identified by DRASTIC and CDRASTIC indexes

Vulnerability	DRASTIC				CDRASTIC			
	Ranges	**Area (km^2)**	**Area (%)**	**The aquifer geographic directions covered by the respective vulnerability**	**Ranges**	**Area (km^2)**	**Area (%)**	**The aquifer geographic directions covered by the respective vulnerability**
Very low	23-46	510.25	25.21	Parts of the south, north, northwest, and northeast	<100	505.02	24.95	Parts of the southeast, north, northwest, and northeast
Low	47-92	775.14	38.31	Parts of the south, southwest, southeast, north, northwest, northeast, and center	100-145	817.70	40.41	Parts of the south, southwest, southeast, north, northwest, northeast, and center
Moderate	93-136	527. 85	26.08	Parts of the south, southwest, northwest, and center	145-190	524.06	25.89	Parts of the south, southwest, southwest, northwest, and center
High	137-184	171.02	8.46	Parts of the northwest	190-235	126.91	6.28	Parts of the northwest and center
Very high	>185	39.23	1.94	Parts of the northwest	≥235	49.79	2.47	Parts of the northwest

3.3. Sensitivity of DRASTIC Model

The MRSA, the DRASTIC index, is performed by eliminating one layer data at a time as indicated in Table 8. The results showed a high variation in vulnerability index when the impact of vadose zone was removed, so that, the average variation index was 1.88%. This shows that the factor is more effective in vulnerability assessment using the DRASTIC index. When this parameter is removed from the overlay process, this leads to a significant decrease in vulnerability index. This could be due to the high theoretical weight assigned to this factor (weight = 5). These findings are similar to those obtained by Dibi et al. (2012) who have shown that, in addition to this parameter, topography, net recharge, and water table depth have a high impact on the vulnerability index. In addition, in Samake et al. (2011), the impact of vadose zone and hydraulic conductivity had a significant impact on vulnerability index, that appears to have a moderate sensitivity to deletion of water table depth (1.48%), net recharge (1.36%), and hydraulic conductivity (1.25%). The minimum menu variation index was achieved after eliminating the aquifer media (0.44%), as indicated in Table 8.

To estimate the effect of individual factors on aquifer vulnerability, the SPSA was performed. A summary of results of SPSA in the DRASTIC index are shown in Table 9. The SPSA compares the effective and theoretical weights. The average effective weight of net recharge was 43.26% and its theoretical weight (%) was 17.4%. This shows that the factor is more effective in vulnerability assessment using the DRASTIC index. The results reported by other studies (Babiker et al., 2005; Doumouya et al., 2012) are similar to those of the present study. The impact of vadose zone and water table depth had high theoretical weights (21.74%); they have been dedicated with an effective weight with average value such as 8.33% and 25.55%. The remaining factors showed an average effective weights of 14.91% (aquifer media), 9.89% (soil media), 11.35% (topography), and 7.01% (hydraulic conductivity). The theoretical weights assigned to water table depth, net recharge, topography, and hydraulic conductivity were not in agreement with the effective weight. The highest and lowest impact on aquifer vulnerability was related to net recharge and hydraulic conductivity, respectively (Table 9).

Table 8 Statistical results of MRSA in the DRASTIC index

The sensitivity of variability index (S) (%)				Removed parameters
SD	Min.	Max.	Ave.	
0.414	0.05	2.36	1.36	D
0.775	0.07	3.06	1.48	R
0.311	0.05	1.31	0.44	A
0.486	0.00	1.65	0.73	S
0.339	0.03	1.31	0.51	T
0.894	0.25	3.84	1.88	I
0.550	0.03	1.98	1.25	C

Table 9 Statistical results of SPSA in the DRASTIC index

Effective weight (%)				Theoretical weight (%)	Theoretical Weight	Parameters
SD	**Min.**	**Max.**	**Ave.**			
6.179	3.23	28.46	8.33	21.74	5	D
11.998	14.06	73.47	43.26	17.4	4	R
3.190	7.26	22.13	14.91	13.04	3	A
2.916	4.49	14.29	9. 89	8.7	2	S
2.222	6.45	14.71	11.35	4.3	1	T
5.367	15.79	37.31	25.55	21.74	5	I
3.738	2.42	18.75	7.01	13.04	3	C

3.4. Sensibility of CDRASTIC index

The MRSA in the CDRASTIC index was performed by eliminating one data layer at a time as indicated in Table 10. The mean variation index of hydraulic conductivity was 4.13%. Hydraulic conductivity had a greater effect on the aquifer vulnerability followed by water table depth (4.05%), soil media (3.82%), topography (3.68%), aquifer media (3.28%), net recharge (2.72%), the impact of vadose zone (2.33%), and land use (1.99%).

The effective weight derived from the SPSA to the CDRASTIC index is shown in Table 11. The average effective weight of net recharge was 32.62%. This shows that the factor is more effective in vulnerability assessment using CDRASTIC index. Hydraulic conductivity displays the lowest effective weights (5.32%). Topography, net recharge, and land use had upper effective weights toward the theoretical weights specified by CDRASTIC index. The average effective weight of land use was 24.82%. This shows that the parameter was the second effective parameter in aquifer vulnerability, using the CDRASTIC index (Table 11).

Table 10 Statistical results of MRSA in CDRASTIC index

The sensitivity of variability index (S) (%)				Removed parameters
SD	Min.	Max.	Ave.	
1.403	0.50	6.48	4.05	D
1.617	0.11	10.91	2.72	R
1.541	0.06	5.99	3.28	A
1.508	0.67	6.60	3.82	S
1.353	0.87	5.87	3.68	T
1.439	0.06	5.12	2.33	I
1.480	0.55	6.72	4.13	C
0.375	1.23	3.00	1.99	L

Table 11 Statistical results of SPSA in CDRASTIC index

Effective weight (%)				Theoretical weight (%)	Theoretical Weight	Parameters
SD	Min.	Max.	Ave.			
4.849	2.63	26.88	6.27	21.74	5	D
10.672	10.4	66.67	32.62	17.4	4	R
3.026	6.29	20.00	11.23	13.04	3	A
2.621	3.31	12.96	7.5	8.7	2	S
1.609	5.2	12.82	8.45	4.3	1	T
4.648	10.87	32.05	19.2	21.74	5	I
3.134	2.1	14. 88	5.32	13.04	3	C
10.122	3.88	42.37	24.82	17.85	5	L

4. Conclusions

Evaluations of vulnerability indexes for the Kerman–Baghin aquifer were conducted using the GIS-based DRASTIC and CDRASTIC indexes. Seven hydro–geological factors (as the letters of the acronym show) were considered in the determination of aquifer vulnerability using DRASTIC, and eight parameters were considered in the CDRASTIC approach. From the DRASTIC index values, it was determined that 10.4% of the aquifer is under high (8.46%) to very high (1.94%) vulnerability. From the CDRASTIC index values, it was determined that 8.75% of the aquifer is under high (6.28%) to very high (2.47%) vulnerability. In addition, we found that parts of the north, south, southeast, and northwest have low to very low vulnerability based on the DRASTIC and CDRASTIC indexes. The MRSA signifies the fact that hydraulic conductivity and the impact of vadose zone induce a high risk of aquifer contamination according to the DRASTIC and CDRASTIC indexes, respectively. For both methods, the SPSA analysis shows that net recharge has a high risk to aquifer contamination. The results of this study showed that parts of the Kerman–Baghin aquifer tend to be contaminate that needs to be considered by regional authorities. Regarding urban planning and the organization of agricultural activities in Kerman Province, the vulnerability map prepared in the study could be the most important when considering protection of groundwater quality. In areas with high and very high vulnerability to groundwater pollution, there should be restrictions on soil fertilization as well as permanent pasture, or afforestation should be introduced in the arable land. In addition, these areas should not be converted into housing developments. In addition, groundwater vulnerability maps of the Kerman–Baghin aquifer are ideal to be used in future land-use planning.

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