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Saltwater intrusion vulnerability assessment using AHP-GALDIT model in Kashan plain aquifer as critical aquifer in a semi-arid region

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Abstract

Owing to population growth and water demand, coastal aquifers all over the world are over–pumped, resulting in serious problems such as saltwater intrusion. So, in these conditions, assessing the groundwater system's vulnerability and finding areas with saltwater intrusion potential are vital for the better management of aquifers. In this study, AHP-GALDIT was applied to saltwater intrusion vulnerability assessment in the Kashan plain. The AHP model determines the weight of each indicator in the GALDIT model. The most important indicators of the AHP model are distance from shore/high tide, groundwater head, groundwater system hydraulic conductivity, impact of present status of saltwater intrusion, saturated media depth, and groundwater occurrence. The AHP-GALDIT distribution map indicates four different rating areas in the Kashan plain, including: more than 10, 7.5 to 5, 5 to 2.5 and less than 2.5, which denote high, average, low, and very low vulnerability, which correspond to approximately 16.16, 25.51, 21.26, and 36.05% of the entire area, respectively. The results reveal that the northeastern part of this inland coastal aquifer is currently undergoing saltwater intrusion. But, it is not clear whether the source of salinity is saltwater intrusion from the "salt lake", upcoming processes, or other sources. This study proves that the GIS-based AHP-GALDIT model is suitable to determine vulnerable sites with high accuracy by using the set of indicators affecting the vulnerability assessment.

Keywords: Inland coastal aquifer; Saltwater intrusion; Vulnerability map; AHP-GALDIT method

1. Introduction

Groundwater constitutes the fresh water available for domestic, industrial and agricultural use (Zehtabian *et al.*, 2013; Mirzavand and Ghazavi, 2015). A wide variety of materials have been identified as pollutants in underground water. The salinization of water resources is one of the most prominent causes of groundwater quality degradation, particularly in arid and semi-arid regions, which renders them useless for drinking, irrigation and industrial purposes (Richter and Kleitler, 1993; Fetter, 1999; Vengosh, 2005, Kheradpisheh *et al.*, 2014, 2015). The most common salinity process, especially in coastal aquifers, is saltwater intrusion. The appropriate way to prevent the groundwater pollution is to identify the vulnerable areas of the aquifer (Mirzavand and Ghazavi, 2015). Groundwater system vulnerability is the appetence of contaminants to stretch on a certain level in aquifers once introduced at a specific site overhead the uppermost groundwater system (Almasri, 2008). Many techniques have been introduced to investigate the vulnerability of a groundwater system, and they can be divided into two categories: the first category includes overlay/index techniques, process-based

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techniques, and numerical techniques, while the second consists of only process-based techniques. In these methods, in order to forecast contaminant transport, simulation techniques are needed; however, the data that these techniques require is not easily obtainable, however, and must thus be predicted using indirect ways. Numerical techniques use statistics to define relations between the specific variables and the actual occurrence of contaminants in the aquifer; however, they are concerned with specific areas and not appropriate for transfer to other areas (Tesoriero *et al*., 1998; Babiker *et al*., 2005). In the overlay/index method, indicators that control the contaminants flow from the earth's surface to groundwater and are mixed with one another. This technique is often cited as the desired method since the needed information is readily available even in large areas, which makes it an appropriate technique in order to evaluate groundwater vulnerability on a regional scale (Jawed *et al*., 2012). The overlay/index techniques consist of DRASTIC, EPIK, SINTACS and GOD which were introduced by Aller *et al*., (1987), Doerfliger *et al*., (1999), Vrba and Zaporozec, (1994), and Foster (1987), respectively. But, one of the new methods among the overlay/index techniques that assesses the vulnerability of groundwater to saltwater intrusion is the GALDIT method. This model evaluates the rate of pollution and saltwater intrusion from the sea to coastal groundwater (Chachadi and Lobo-Ferreira, 2001), and is used by many researchers around the world for important groundwater systems, such as the Monte Gordo groundwater system in Portugal, Greek coastal aquifers (Chachadi and Lobo-Ferreira, 2001; Lobo Ferreira *et al*., 2005; Pedreira *et al*., 2015), India (Kallioras *et al*., 2011; Kanani *et al*., 2017), Kapas Island in Malaysia (Kura *et al*., 2015), Finland (Luoma *et al*., 2017), the United States of America (Tasnim and Tahsin, 2016), and the Tunisian coast (Santha Sophiya and Syed, 2013; Gontara *et al*., 2016: Trabelsi *et al*., 2016). The GALDIT model was also used to assess the saltwater intrusion from Urmia Lake into the coastal aquifer in Iran. (Nakhaei *et al*., 2015; Docheshmeh Gorgij and Asghari moghaddam, 2016). Kardan Moghadam *et al*., (2017), compared the DRASTIC and GALDIT methods in the assessment of coastal aquifer vulnerability and showed that the GALDIT method had better results and higher correlation with TDS based on the Pearson test compared to the DRASTIC method. The weight of every parameter in the aquifer adjacent to the inland saline lakes could be different from the coastal aquifer near the sea and ocean waters, due to the different hydrogeological settings. The main objective of this study is to use the modified AHP-GALDIT model to study the intrinsic vulnerability of saltwater intrusion (IVSI) in the Kashan aquifer.

2. Materials and Methods

2.1. Study Area

The Kashan plain aquifer (KPA) is located in Isfahan province in central Iran and occupies an area of about 1570.23 km^2. Morphologically, it is composed of a plain surrounded by mountains. The exposed geological formations are listed in descending order of age as follows: the Eabvt (Andesitic to basaltic volcanic tuff), E2l (Nummulitic limestone) and Edav (Dacitic to Andesitic volcanic) from the lower Eocene, Ekgy (Gypsum) from the upper Eocene, Olgy (Gypsum) and OMav (Andesitic volcanic) from the Oligocene, OMql (Massive to thick - bedded reefal limestone) from the upper Oligocene to lower Miocene, Mur (Upper red) (sandstone, gypsiferous marl, conglomerate, and Red marl) and Murc (sandstone and Red conglomerate) from the upper Miocene, Plc (sandstone, Polymictic conglomerate, and Rhyolitic to rhyodacitic volcanic) from the Pliocene and Qft2 (terrace deposits and Low level piedmonts fan), Qft1 (High level piedmont fan and valley terrace deposits), Qcf (Clay flat), Qal (braided channel, Stream channel, and flood deposits), Qs.d (wind-blown deposits consist of sand dunes) and OMq (QOM FM) (gypsiferous marl, Limestone, sandstone and sandy marl) from the Quaternary period (Fig. 1).

The KPA is located in the Quaternary alluvial plain. The deposits in the center of the area are mainly sandy loam and silt, while the sediments near the margins are gravel and sand. Shallow groundwater mainly lies 50m below the surface, and its flow direction is generally from the west to the east of the plain, but in the northeast of the aquifer the flow direction changes from north to south (Fig.2).

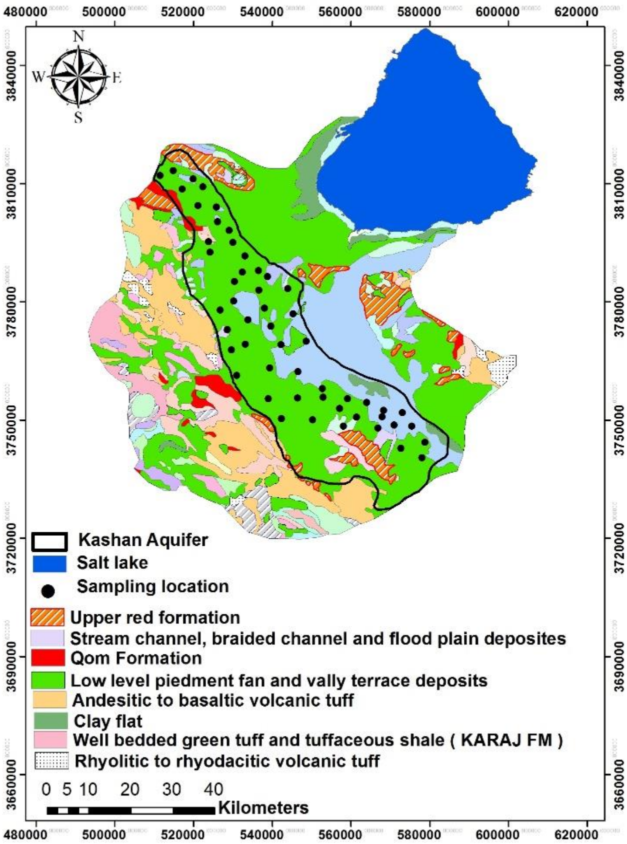

Fig. 1. Mineralogy map and sampling wells' location in Kashan plain

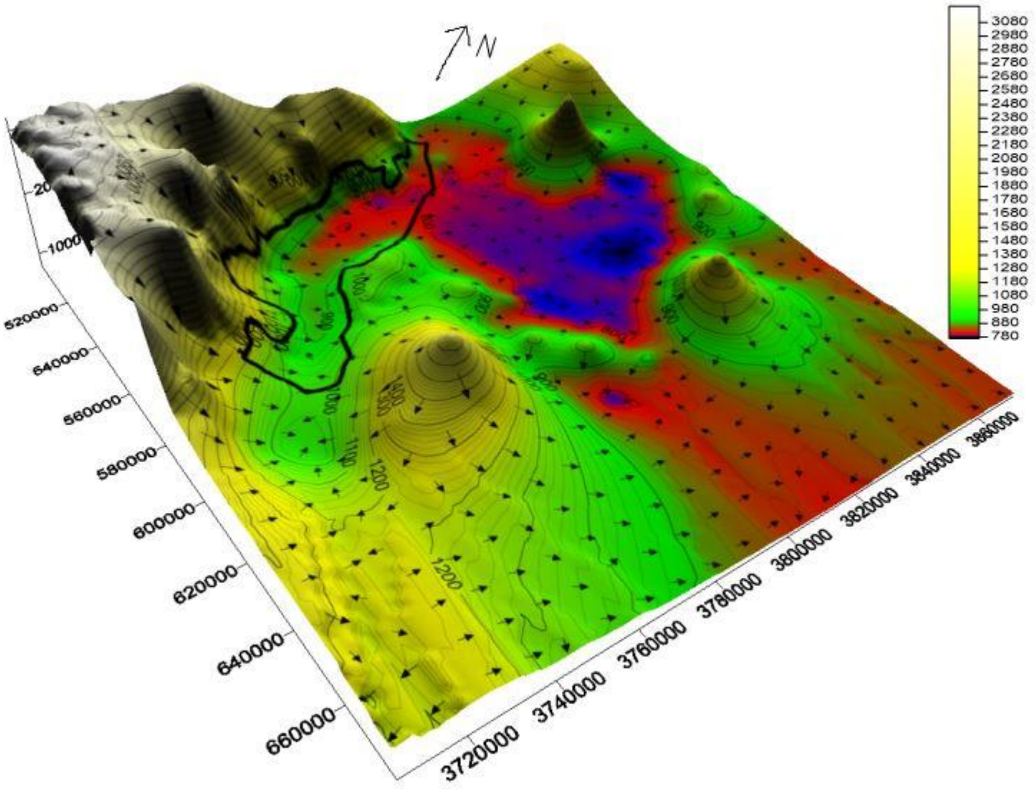

Fig. 2. Groundwater flow direction with Salt Lake and aquifer boundary

A salt lake, called Aranbidgols, is situated near the eastern part of the Kashan plain. Therefore, this aquifer can be considered an inland coastal aquifer. This salt lake has an area of 2000 km^2 and average depth of 50m, with a 1-meter drop in average annual groundwater that reduces the annual water volume to about 32 Mm^3. This negative annual water budget has changed the hydraulic gradient, and consequently the flow direction, from the salt lake to the aquifer. Therefore, the eastern part of the plain is affected by saltwater intrusion via the salt lake, thus decreasing water quality. Also, due to the occurrence of the Qom salt formations and the presence of Qom's saline aquifers near the plain, the quality of the water is seriously jeopardized. The mean annual precipitation is approximately 132 mm with a peak between December and February. The mean annual temperature and evaporation are 19 °C and 3000 mm, respectively.

2.2 GALDIT model description

The GALDIT model was developed by Chachadi and Lobo-Ferreira in 2001, then revised in 2005 and is–specialized for coastal aquifers. This model is based on six hydrogeological factors: groundwater occurrence (G), groundwater system hydraulic conductivity (A), water table head (L), distance from shore line (D), impact of present status of saltwater intrusion (SI) (I), and saturated media depth (T).

The Remote Sensing (RS) and Geographic Information System (GIS) methods were used to draw the vulnerability map of the Kashan inland coastal aquifer, based on the Analytic Hierarchy Process (AHP) technique and the GALDIT model. RS tools, like aerial photos, were used for classification of geological features, topography, and distribution of the hydrology network in KPA. The mineralogy maps and on-site exploration were implemented to qualitatively and quantitatively study the hydro-geological situation of the study area. The essential maps, including the type of aquifer system (unconfined, confined, or leaky confined), aquifer hydraulic conductivity, water table head, and aquifer depth generated. These maps contain the important parameters affecting the potential of the SI into the aquifer and consequently affecting the groundwater vulnerability map, using GIS tools combined with satellite information and other collateral data. The weighing values of each parameter were allotted based on on-site characteristics. The weight assigned to each indicator, which represents the relative importance of that indicator in the SI process (GLDIT model) and the vulnerability map, was calculated based on the AHP system.

3. Results and Discussions

The GALDIT model is an Overlay technique that assesses the vulnerability of groundwater due to saltwater intrusion using six environmental indicators;

3.1. The proposed AHP-GALDIT model for assessing KPA vulnerability

The main intrinsic hydrogeological properties of the groundwater system are the physical features of the media, which affect the potential of saltwater intrusion and the vulnerability map (Chachadi and Lobo-Ferreira, 2001). GALDIT is abbreviated from six hydrogeological factors: groundwater occurrence (G), groundwater system hydraulic conductivity (A), water table head (L), distance from shore line (D), impact of present status of saltwater intrusion (SI) (I), and saturated media depth (T). The mentioned parameters in the GALDIT model are the most imperative parameters that influence SI in coastal aquifers.
The KPA is an inland coastal aquifer near the Kashan Salt Lake; therefore, due to different hydrogeological setting, the weights of the GALDIT factors should be changed according to the importance of the factor and saltwater intrusion potential. The factors in the GALDIT model were calculated based on the AHP technique according to theirweight (Tables 1 to 5).

3.2. Factors influencing the GALDIT model

Mainly six factors influence SI in the GALDIT model.

3.2.1. Groundwater occurrence/aquifer type:

Groundwater typically appears in porous geological formations and can create three types of aquifers: confined, unconfined, and leaky confined. SI is dependent upon the aquifer system's characteristics. Based on the GALDIT model, the rating rank for all parameters ranges from 2.5 to 10, from lowest to highest vulnerability. The Kashan basin is composed of an unconfined aquifer system, hence a GALDIT ranking score of 7.5 was allocated for the Kashan aquifer (Table 5 and Fig. 3_f).

Table 1. Saaty's rank for weight assignment and its attribution (Saaty, 1980)

	Low importance				Equally importance		High importance			
Extremely	Strong preferences between intervals	Very intensely	Intensely	Temperately	Equally important	Temperately	Intensely	Very intensely	Strong preferences between intervals	Extremely
1/9	1/2, 1/4, 1/6, 1/8	1/7	1/5	1/3	1	3	5	7	2, 4, 6, 8	9

Table. 2. A matrix of pair-wise evaluations of 6 parameters for the AHP method

Indicators	G	A (m/day)	L (m)	D (m)	I	T(m)
G	1	3	5	7	8	9
A (m/day)	1/3	1	3	5	7	8
L (m)	1/5	1/3	1	3	5	7
D (m)	1/7	1/5	1/3	1	3	5
I	1/8	1/7	1/5	1/3	1	3
T (m)	1/9	1/8	1/7	1/5	1/3	1
Column total	1.908	4.797	9.672	16.53	24.33	33

Table. 3. Determining the relative criterion weights

Indicators	w_{ij} (j=1)	w_{ij} (j=2)	w_{ij} (j=3)	w_{ij} (j=4)	w_{ij} (j=5)	w_{ij} (j=6)	$Weights = \frac{1}{n}\sum Wij$
G	0.524	0.627	0.516	0.423	0.328	0.272	0.448
A (m/day)	0.173	0.209	0.310	0.302	0.287	0.242	0.253
L (m)	0.104	0.069	0.103	0.181	0.205	0.212	0.145
D (m)	0.074	0.041	0.034	0.060	0.123	0.151	0.080
I	0.065	0.029	0.020	0.019	0.041	0.090	0.044
T (m)	0.057	0.023	0.014	0.012	0.013	0.030	0.024
Column total	1	1	1	1	1	1	1

Table. 4. Determine the CR

Indicators		CV
G	1 (0.448) + 3 (0.253) + 5 (0.145) + 7 (0.08) + 8 (0.044) + 9 (0.024) = 3.06	3.06/0.448=6.83
A (m/day)	0.33(0.448) + 1(0.253) + 3(0.145)+ 5(0.08) + 7(0.044) + 8(0.024) = 1.73	1.73/0.253=6.83
L (m)	0.2(0.448) + 0.33(0.253) + 1(0.145)+3(0.08) + 5(0.044) + 7(0.024) = 0.94	0.94/0.145=6.48
D (M)	0.142(0.448) + 0.2(0.253) + 0.33(0.145) + 1(0.08) + 3(0.044)+ 5(0.024) = 0.49	0.49/0.08= 6.12
I	0.125(0.448) + 0.142(0.253) + 0.2(0.145) + 0.33(0.08) + 1(0.044) + 3(0.024) = 0.26	0.26/0.044=5.9
T (m)	0.11(0.448) + 0.125(0.253) + 0.142(0.145) + 0.2(0.08) + 0.33(0.044) + 1(0.024) = 0.15	0.15/0.024=6.25

Table. 5. Normalized AHP weight and importance rating for indicators

Indicators	Normalized AHP Weight	Indicator variables		Rank rating
		Category	Range	
Groundwateroccurrence/aquifer type	0.024	Confined		10
		Unconfined		7.5
		Leaky		5
		Bounded aquifer		2.5
Hydraulic Conductivity (m/day)	0.145	High	>40	10
		Medium	10-40	7.5
		Low	5-10	5
		Very low	<5	2.5
Height of ground water level than to Salt lake (m)	0.253	High	1>	10
		Medium	1.5-1	7.5
		Low	2-1.5	5
		Very low	2<	2.5
Distance from shore/ high tide (m)	0.448	Very small	500>	10
		small	500-750	7.5
		Medium	750-1000	5
		Far	1000<	2.5
Impact of present saltwater intrusion	0.08	High	>2	10
		Medium	1.5-2	7.5
		Low	1.5-1	5
		Very low	<1	2.5
Aquifer thickness (Saturated) (m)	0.044	High	>10	10
		Medium	7.5-10	7.5
		Low	5-7.5	5
		Very low	5>	2.5

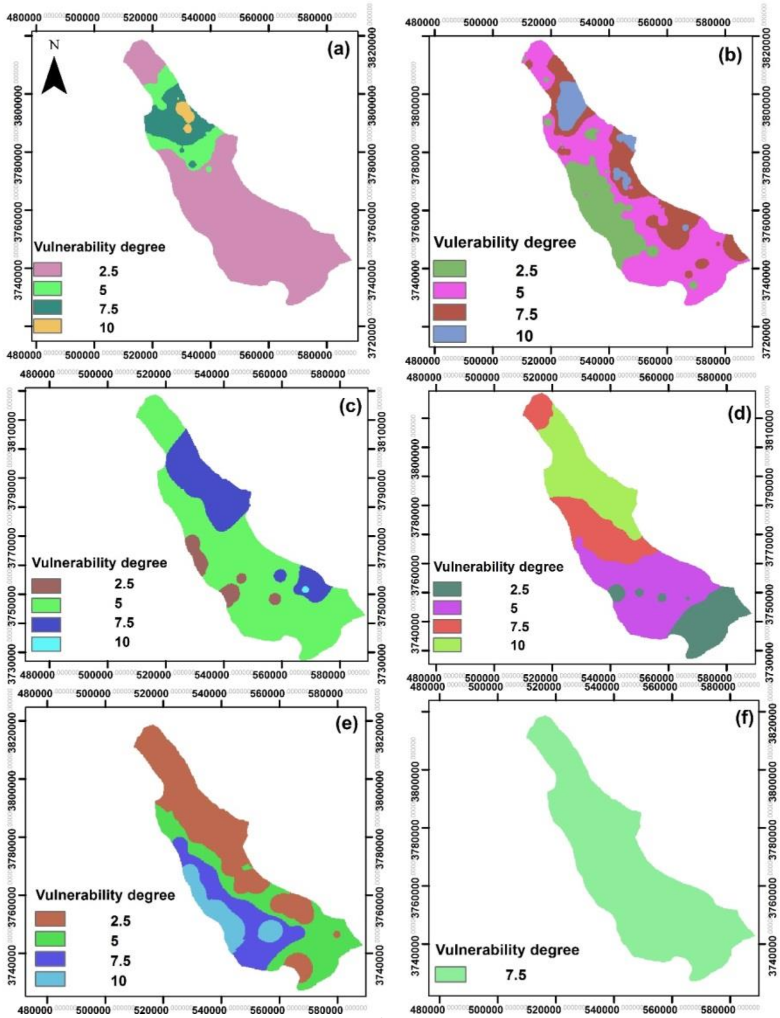

Fig. 3. Vulnerability map of L, I, T, D, A and G indicator

3.2.2. Groundwater system hydraulic conductivity (A)

The ability of water to pass through pores or fractures in the soil, based on the hydraulic gradient, is named hydraulic conductivity (Chachadi and Lobo-Ferreira, 2001). Chachadi, (2005) states that the spreading of the saline waterfront under constant hydraulic pressure is related to the hydraulic conductivity of the groundwater system; therefore greater hydraulic conductivity makes for more extended inland transport of the saltwater zone. For hydraulic conductivity, the GALDIT model rating stretches from 2.5-10, expressing the lowest to highest hydraulic conductivity in groundwater systems (Table 5 and Fig. 3_e). The southwest and west sides of the KPA are composed from gravel and coarse particles, but the northeast and east sides are composes from sand, which translates to a decrease in hydraulic conductivity toward the east and northeast of the KPA.

3.2.3. Water Table head (L)

As mentioned by researchers such as Kallioras *et al*., (2011); Pedreira *et al*., 2015; Kura *et al*., (2015); Kanani *et al*., (2017); and Luoma *et al*., (2017), this indicator is the most imperative parameter in the evaluation of saltwater intrusion inside a groundwater system, since it determines the extent of the boundaries between salt and fresh water and their shape (Chachadi, 2005). The Ghyben–Herzberg equation asserts that for every 1m of freshwater stored above sea level, the column of freshwater moves 40m downward toward the saltwater and freshwater boundary. The information on water table levels is categorized into ranges and rankings belonging to indicator L in the GALDIT model. So, the ranking scores change from 2.5 to 10, indicating the lowest to highest levels of the water table head (Table 5 and Fig.3_a). As shown in Figure (3a), the lowest water head is in northeast of the KPA, which is the aquifer's discharge zone.

3.2.4. Distance from shore/ high tide

The saltwater intrusion reaches its maximum rate in the aquifer near the coast where the aquifer's hydrogeological characteristics for transition are suitable. This indicator was determined by use of the aquifer's boundary, pumping well locations and the boundaries of the salt lake. So, in this model, the ranking scores for the distance from the shore change from 2.5 to 10, from highest to lowest distance, respectively (Table 5 and Fig.3_d).

3.2.5. The impact of present status of saltwater intrusion (I)

This indicator represents the occurrence of SI in a specific area, which is determined from field information. In the GALDIT model, this indicator is known as the Revelle ratio $Cl/(HCO_3+CO_3)$. Therefore, the change in the ranking scores occurs by the change of SI from 2.5 to 10, for lowest to highest chloride concentration, respectively (Table 5 and Fig.3_b). It should be noted that by moving to the discharge zone and shoreline of the coastal aquifer, the Revelle ratio should increase, but the source of this salinity may be due to upconing, and not saltwater intrusion from the salt lake, as both would increase the Revelle ratio when nearing the discharge zone. Thus, hydrogeochemical and isotopic investigation is necessary for more accuracy, a fact not mentioned by Chachadi and Lobo-Ferreira, (2001) and other researchers such as Tasnim and Tahsin, (2016); Kanani *et al*., (2017); and Luoma *et al*., (2017).

3.2.6. Saturated media depth (T)

In coastal groundwater systems, this indicator is essential in the transfer of SI into ground water (Chachadi, 2005). Thus, in this model, the ranking scores change with the thickness of the aquifer, from 2.5 to10 (Table 5 and Fig.3_c).

3.3. AHP-GALDIT Vulnerability Model

The AHP-GALDIT model is determined by adding and multiplying each indicator's weight with its site rating, as demonstrated by the following equation:

$$AHP-GALDIT=\frac{\sum_{i=1}^{6}((\frac{1}{n}\sum Wij)R_i)}{\sum_{i=1}^{6}\frac{1}{n}\sum Wij} \qquad \text{Eq. (4)}$$

where $\frac{1}{n}\sum Wij$ is the weight of the ij^{th} parameter in table (3) and R_i is the prominent score of the i^{th} parameter. The weights and ranking scores of the effective factors in the GALDIT model for the KPA are given in Table 5.

The Consistency indicator (CI), which is the amount of departure from stability, was measured via the equation (1):

$$C.I = \frac{\lambda - n}{n - 1} \qquad (1)$$

Where n and λ are the number of parameters (i.e. 6) and mean rate of the consistency vector (CV), respectively.

Based on equation (2), the consistency ratio (CR) is equal to consistency indicator (CI) divided by the random indicator (RI):

$$CR = \frac{CI}{RI} \qquad (2)$$

In equation (2), the RI value is related to the number (n) of parameters being compared. The normalized AHP weights of 0.448, 0.253, 0.145, 0.08, 0.044 and 0.024 (i.e. 44.8%, 25.3%, 14.5%, 8%, 4.4% and 2.4% respectively) can be assigned to the following factors: distance from shore line (m), height of ground water level (m), hydraulic conductivity (m/day), aquifer saturated thickness (m), and groundwater occurrence/aquifer. It should be noted that, each aquifer has its own condition and so, the priority of the parameters in the GALDIT model could be different for each area. But in general, in most aquifers investigated by researchers such as Lobo Ferreira *et al*., 2005; Kallioras *et al*., 2011; Pedreira *et al*., 2015; Kura *et al*., (2015); Kanani *et al*., (2017); and Luoma *et al*., (2017), the most important parameter was the height of groundwater level, which has proven to be the second most important factor in this study.

Fig. 4 illustrates the vulnerability map of the Kashan plain, generated based on the AHP-GALDIT model, demonstrating saltwater intrusion to the KPA from the adjacent salt lake. This model divides the KPA into four different areas with the following ratings: more than 10, 7.5 to 5, 5 to 2.5, and lower than 2.5, denoting high, average, low and very low vulnerability, respectively. These four areas correspond to approximately 16.16%, 25.51%, 21.26% and 36.05% of the entire KPA, respectively. The groundwater table is lower in the northwest, west and the center of the plain due to high groundwater extraction. Therefore, this factor is the determining cause for the change in groundwater direction in these areas and the resulting saltwater intrusion. But the source of this salinity is not clear and further tests are recommended.

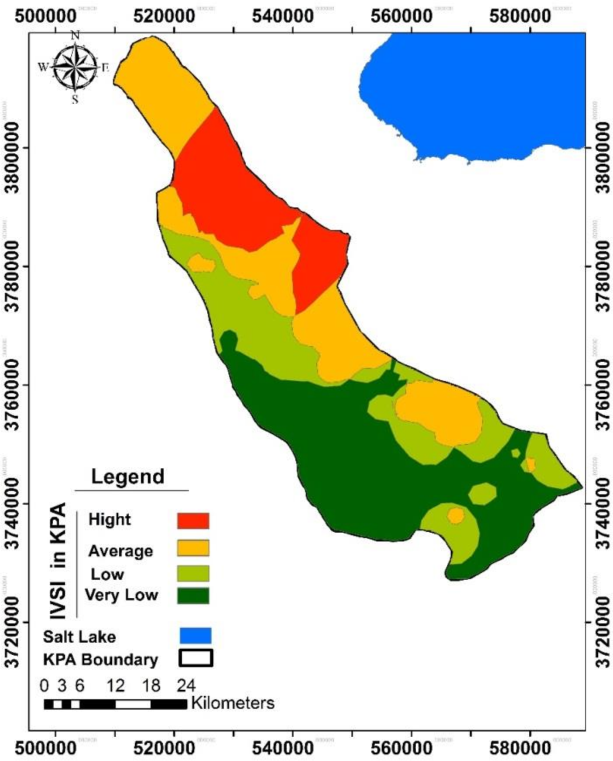

Fig. 4. Intrinsic vulnerability to salt water intrusion map of Kashan plain using AHP-GALDIT model

4. Conclusion

The groundwater quality of coastal aquifers is at risk of salinization due to saltwater intrusions. So, determining the vulnerability of this area to saltwater intrusion is vital for aquifer management. The GALDIT model and AHP techniques through GIS are used to evaluate the potential saltwater intrusion sites in KPA. The KPA is an inland coastal aquifer near the salt lake. Six environmental indicators, including groundwater type (G), groundwater system hydraulic conductivity (A), water table head (L), distance from the shore line (D), impact of present status of saltwater intrusion(I), and saturated media depth (T), were used to determine the vulnerability map. These factors in the GALDIT model, according to the degree of weight, were calculated using the AHP technique. The results reveal that the northeastern part of this inland coastal aquifer is currently undergoing saltwater intrusion. The groundwater table, which is lower than sea level, and located in the northeast, is the main cause of the saltwater intrusion. Based on this model, it is not possible to find the source(s) of salinity in the aquifer, but it is possible to find the area(s) with high salinity potential and for the identification of the source (s) of salinity. In order to achieve this, isotopic and hydrogeochemical investigations are necessary. Consequently, this study shows that the GIS-based AHP-GALDIT model is suitable to determine vulnerable sites with high accuracy and can be applied to different coastal regions.

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References

Aller, L., T. Bennett, J.H. Lehr, R.J. Petty, G. Hackett, 1987. DRASTIC: a standardized system for evaluating groundwater pollution using hydrogeologic settings. EPA, 600/2-87-035.

Almasri, M.N., 2008. Assessment of intrinsic vulnerability to contamination for Gaza coastal aquifer, Palestine. Journal of Environmental Management, 88; 577-593.

Babiker, I.S., A.A. Mohamed, T. Hiyama, K. Kato., 2005. A GIS-based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, central Japan. Science of the Total Environment, 345; 127–140.

Bilgehan, N., A. Berktay, 2006. Groundwater contamination by nitrates in the city of Konya: A GIS perspective. Journal of Environment Management, 79; 30-37.

Chachadi, A.G., 2005. Seawater intrusion mapping using modified GALDIT indicator model-case study in Goa. Jalvigyan Sameek, 20; 29-45.

Chachadi, A.G., J.P. Lobo Ferreira, 2001. Seawater intrusion vulnerability mapping of aquifers using the GALDIT method. Coastin, 4; 7-9.

Docheshmeh Gorji, A., A. Asghari Moghadam, 2017. Assessment of Saltwater Pollution in Azarshahr Plain Groundwater, Iran: Conjugating GALDIT Method and Geostatistics. Journal of Water Sciences Research, 9; 63-72.

Doerfliger, N., P.Y. Jeannin, F. Zwahlen, 1999. Water vulnerability assessment in karst environments: a new method of defining protection areas using a multi-attribute approach and GIS tools (EPIK method). Environmental Geology, 39; 165–176

Fetter, C.W., 1999. Contaminant Hydrology. Prentice-Hall, Englewood Cliffs, NJ.

Gontara, M., N. Allouche, I. Jmal, S. Bour, 2016. Sensitivity analysis for the GALDIT method based on the assessment of vulnerability to pollution in the northern Sfax coastal aquifer, Tunisia. Arabian Journal of Geoscinces, 9; 416. DOI 10.1007/s12517-016-2437-3

Jawed, I., A.K. Gorai, T. Poonam, P. Gopal, 2012. Approaches to groundwater vulnerability to pollution: a literature review. Asian Journal of Water Environment and Pollution, 9; 105–115.

Kallioras, A., F. Pliakas, S. Skias, I. Gkiougkis, 2011. Groundwater Vulnerability assessment at SW Rhodope aquifer system in NE Greece, Advances in the Research of Aquatic Environment, 2; 351-358.

Kardan Moghaddam, H., F. Jafari, S. Javadi, 2017. Vulnerability evaluation of a coastal aquifer via GALDIT model and comparison with DRASTIC index using quality parameters. Hydrological Sciences Journal, 62; 137-146. DOI.org/10.1080/02626667.2015.1080827

Kanani, T.J., A.M. Malek, I. Prakash, Kh. Mehmood, 2017. Ground Water Vulnerability Assessment of Coastal Area of Porbandar, Gujarat, India. International Journal for Scientific Research & Development, 5; 796-799.

Kheradpisheh, Z., S.A. Almodaresi, Y. Khaksar, L. Rafati, 2014. Zoning of Groundwater Contaminated by Nitrate Using Geostatistics Methods (Case Study: Bahabad Plain, Yazd, Iran). Desert, 19; 83-90.

Kheradpisheh, Z., A. Talebi, L. Rafati, M.T. Ghaneeian, M.H. Ehrampoush, 2015. Groundwater quality assessment using artificial neural network: A case study of Bahabad plain, Yazd, Iran. Desert, 20, 65-71.

Krishnaswami, S., R. Bhushan, M. Baskaran, 1991. Radium isotopes and 222Rn in shallow brines, Kharaghoda (India). Chemical. Geology. Isotope. Geoscience. Section, 87; 125–136.

Kura, N.U., M.F. Ramli., S. Ibrahim., W.N. Sulaiman., A.Z. Aris., A.I. Tanko., M.A. Zaudi, 2015. Assessment of groundwater vulnerability to anthropogenic pollution and seawater intrusion in a small tropical island using index-based methods. Environmental Science and Pollution Research, 22;1512-33.

Lobo-Ferreira, J.P., A.G.C. Chachadi Diamantino, M.J. Henriques, 2005. Assessing aquifer vulnerability to seawater intrusion using GALDIT method: Part 1 – Application to the Portuguese Aquifer of monte Gordo, The forth Inter-Celetic colloquium on the hydrology and management of water resources, Guimaraes, Portugal. pp.1-12.

Luoma S., J. Okkonen, K., Korkka-Niemi, 2017. Comparison of the AVI, modified SINTACS and GALDIT vulnerability methods under future climate-change scenarios for a shallow low-lying coastal aquifer in southern Finland. Hydrogeology Journal, 25; 203–222.

Mirzavand, M., R. Ghazavi, 2015. A stochastic modelling technique for groundwater level forecasting in an arid environment using time series methods. Water Resources Management, 29;1315-1328.

Nakhaei, M., M. Vadiati, Kh. Mohammadi, 2015. Evaluation of Vulnerability of Urmia Lake Saline Water Intrusion to Coastal Aquifer Using GALDIT Model. Scientific Quarterly Journal, Geosciences, 24; 223-230.

Pedreira, R., A. Kallioras, F. Pliakas, I. Gkiougkis, C. Schuth, 2015. Groundwater vulnerability assessment of a coastal aquifer system at River Nestos eastern Delta, Greece. Environmental Earth Sciences, 73; 63-87.

Richter, B.C., C.W. Kreitler, 1993. Geochemical techniques for identifying groundwater salinisation. CRC press, Boca Raton.

Saaty, T.L., 1980. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill, New York.

Santha Sophiya, M., T.H. Syed, 2013. Assessment of vulnerability to seawater intrusion and potential remediation measures for coastal aquifers: a case study from eastern India. Environmental Earth Sciences, 70; 1197-1209.

Tasnim, Z., S. Tahsin, 2016. Application of the Method of Galdit for Groundwater Vulnerability Assessment: A Case of South Florida. Asian Journal of Applied Science and Engineering, 5; 27-40.

Tesoriero, A.J., E.L. Inkpen, F.D. Voss, 1998. Assessing groundwater vulnerability using logistic regression. Proceedings for the Source Water Assessment and Protection 98 Conference, Dallas, TX, 157–165.

Trabelsi, N., I. Triki, I. Hentati, M. Zairi, 2016. Aquifer vulnerability and seawater intrusion risk using GALDIT, GQISWI and GIS: case of a coastal aquifer in Tunisia. Environmental Earth Sciences, 75; 669 -710.

Vengosh, A., 2005. Salinization and saline environments, in: Sherwood Lollar, B., Holland ,H.D.

Vrba, J., A. Zaporozec, 1994. Guidebook on mapping groundwater vulnerability, International Contributions to Hydrology. Heinz Heise, Hannover.

Zehtabian, Gh.R., H. Mohammad Asghari, M. Tahmoures, 2013. Assessment of Spatial Structure of Groundwater Quality Variables Based on the Geostatistical Simulation. Desert, 17; 215-224.