COMPARING VULNERABILITY DELINEATIVE OF AQUIFER USING DRASTIC AND FUZZY LOGIC METHODS (CASE STUDY: GULGIR PLAIN OF MASJED SOLIEMAN, IRAN)

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Abstract

Various vulnerability evaluation systems are developed for proper and effective prevention of future groundwater pollutions. Presently, there are different methods to detect the contamination potentiality of the ground water. The present research evaluates the vulnerability delineative of Gulgir Plain aquifer. This plain is located on the east of Khuzestan Province. Due to its rich groundwater resources and fertile soil the plain enjoys a flourishing agriculture. However, due to massive agricultural activities the quality of the groundwater has been exposed to agricultural pollutions particularly Nitrates. The DRASTIC model and fuzzy Inference were chosen from the myriad of vulnerability evaluation methods. Principles of the DRASTIC model are based on the combination of hydrological and hydro-geological indexes that affect the transmission or non-transmission of contaminations and Boolean Logic is used to calculate the indexes. The Boolean logic may result in erroneous conclusions about the quantities that proximate the borders. The fuzzy logic, however can improve the accuracy of results particularly concerning the border quantities. Therefore, this method has been used in the present research and the results are compared to those of the Boolean logic. The results confirm the power of fuzzy modeling in determining hydrogeological parameters which lack assurance.

Keywords: Vulnerability, Delineative, DRASTIC, Fuzzy logic

INTRODUCTION

Ground water is considered as important resource due to the lower potentiality of contamination as well as a high reserve capacity compared to the surface water (US EPA, 1996). The major sources of spot and dispersive contaminants arising from human activities on the ground and penetration of these contaminants into the ground tend to reduce the quality of the ground water. Therefore, preventing the ground water from contamination is essential to the management of ground water resources (Melloul & Collin, 1994). Evaluation of vulnerability is a proper and low cost method for detection of the areas which are apt to contamination. The concept of vulnerability was proposed in France to give information on contamination of ground water for the first time at the end of 1960 (Vrba & Zaporopzec, 1994). Vulnerability may be defined as the possibility of penetration and dispersion of contaminants from the earth surface into the ground water system. Vulnerability is considered as an inherent apt of the ground water which depends on the extent of sensitivity of this system to the impacts of the human or natural activities. Vulnerability is divided into two inherent and special categories in term of meaning. The inherent vulnerability means sensitivity of ground water to the natural elements while special vulnerability studies the inherent vulnerability together with the probability of exposure of the ground waters to penetration of contaminants.

One of the methods that greatly help the management of ground waters is to prepare maps in which the areas vulnerable or sensitive to contamination have been located. Moreover, an index is also defined to identify those areas that are more exposed to contaminants than others. In this way we can compare different areas with each other and find a single criterion for evaluation.

The maps and data should be combined and classified in order to Boolean the results and calculate the index of vulnerability. These classifications are usually based on the Boolean Method. In this classification the border between the classes should be specified. Whereas the vulnerability indexes are of spectral and extensive nature, the classification on the basis of the Bolin method causes an area to be relocated from one class to an upper class or a lower class with a slight change, something which is not principally acceptable and justifiable. However, by using the foundations of the fuzzy theory in which each and every subject and concept has a membership grade a suitable method may be offered for classification and rating as compared with the Boolean method (Malano & Gao, 1992). The present analysis is aimed at identification of the areas in the subterranean water of Gulgir Plain that are apt to contamination, and examining the possibility of applying the fuzzy logic for classification of the vulnerability maps.

Situation and general features of the study plain

The Gulgir plain is situated in Masjed Soleiman region within the geographical longitude 49° 27′ 30″and 49° 31′ 19″ and the geographical latitude 31° 44′ 05″ and 31° 47′ 01″ with an area of about 1600 hectares. It is located in the middle of Karoun basin (Fig. 1).

The area of the alluvial subterranean water of Gulgir Plain is approximately 24.48 square kilometers. Gulgir, Tambi, Bahramabad, Hajiabad, Shamsabad, and Sazbabad villages are among the major population center in Gulgir Plain. Access to the plain is possible through Ahwaz-Izeh-Masjed Soleiman-Haftgel main roads. Regional streams include Shour Tambi, Ab Gulgir, Ab Lashgar, Shour Barik, Bid Zard and Darreh Kouh la.

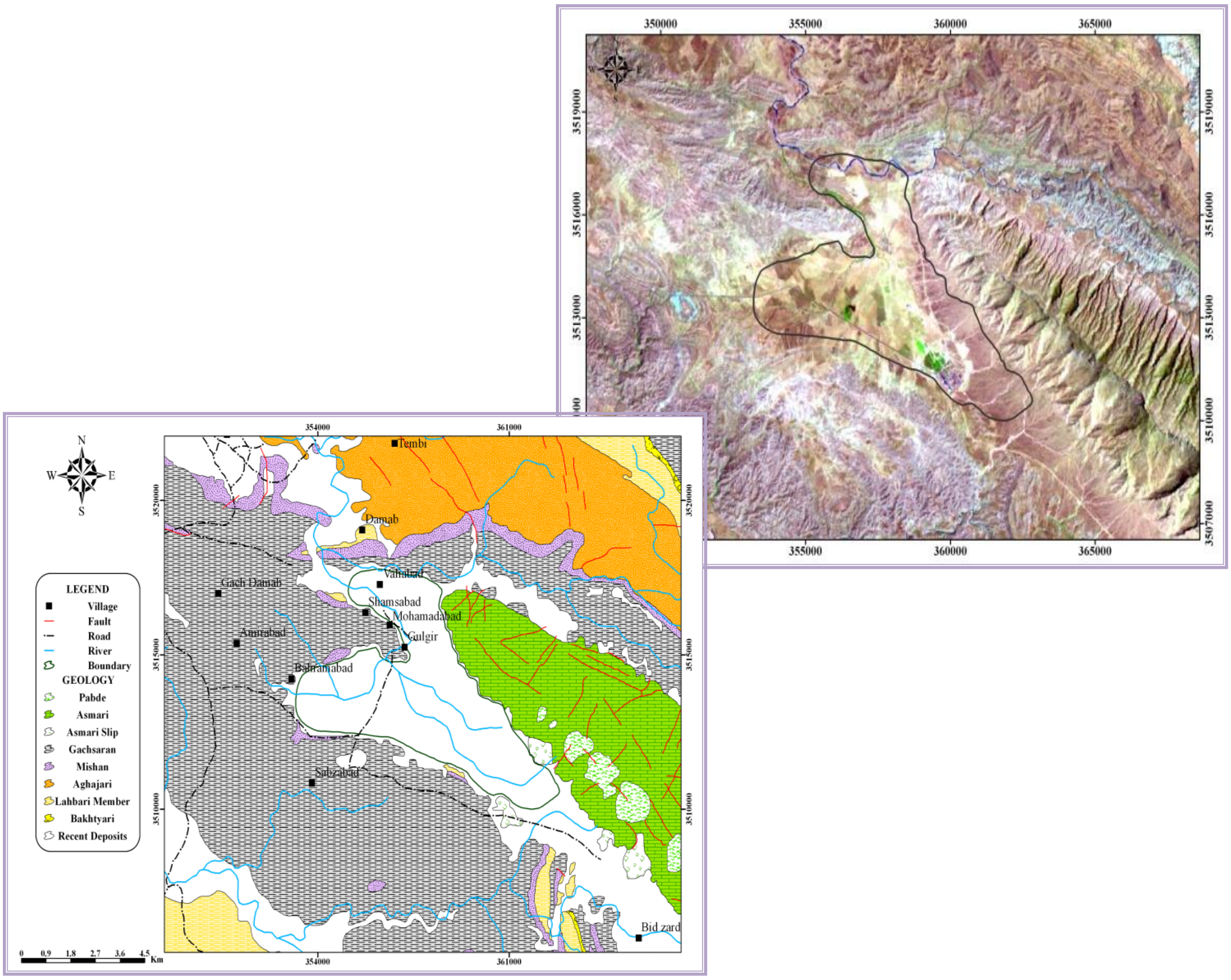


Fig. 1. Geological map and satellite image of Gulgir Plain

Study method

The DRASTIC method and fuzzy model have used in order to calculate the extent of vulnerability of the ground water of Gulgir Plain. The extent has been calculated in the GIS domain. The research has used various information sources including topographic maps with a scale of 1:25000 (by Army Geographical Organization), geological map with a scale of 1:100000 (by state Geological and Mineral Explorations Organization), report of the pedological studies of Gulgir Masjed Soleiman (state Water and Soil Engineering Service Company-Management of Karkheh Studies), data on the level of ground water, results of the pumping tests, excavation log of the observation-exploration wells and maps of geo-physical studies. The map information (like the topographic map) was described in numbers and put into the geographical information system while table information (such as depth to water table) was changed into the data bank format and loaded into the data base. The fuzzy model was employed in this research using MATLAB 7.6.0 software based on the Mamdani minimum - maximum fuzzy Inference, which has the widest application in scientific problems due to its simple and effective structure, and defuzzifier making Center of gravity method. The Gaussian membership function was used for fuzzifier making due to its simplicity.

DRASTIC Model

There are different methods for estimation of the vulnerability of ground water. One of these methods is overlay – index method which combines the elements controlling the movement of the contaminants from the ground surface to the saturated zone and shows the result as a vulnerability index in different spots of the region under the study. One of the models that are widely used to evaluate the vulnerability of the ground water regarding a wide range of potential contaminants is DRASTIC model. The model is the most common overlay – index method which has been developed by the United States Environment Protection Agency (USEPA) and American Water Well Association (AWWA) to determine the contamination potentiality of the ground water. By collecting the key factors affecting the transfer of soluble materials, the model evaluates the contamination potentiality of a region. DRASTIC model calculates the potential contamination of the ground water using seven factors affecting them. These factors are: Depth to water table, Net Recharge, Aquifer media, soil media, Topography, Impact of vadose zone media, and Hydraulic conductivity (Aller et al., 1987). These seven parameters do not have equal impacts. As for the topic of vulnerability some of these parameters are more important than others. Consequently, each factor is given a relative weight between 1 and 5 based on its relative importance compared to other factors. Among the cited depth to water table and vadose zone media have the most value and Topography slop has the lowest value parameters. Each parameter is also divided into spans with different effect on contamination potentiality. Each span is given a rate between 1 and 10 (10 for highest effect and 1 for lowest effect). The result of the DRASTIC model is a numerical index which is deducted from the rates and weights allocated to the parameters of the model. To calculate the DRASTIC index equation 1 is used:

$$\text{DRASTIC Index} = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W \quad (1)$$

Where weight **(W)** and rate **(R)** relate to each of the model's parameters. Upon calculation of the DRASTIC index the vulnerable areas of the ground water are located. We should notice that this index would offer only a relative evaluation and would only distinguish the seriously vulnerable areas from those with lower vulnerability without the capability of an absolute assessment.

Preparation of standard maps of the model

A standard map shows the extent of relativity of a feature to the target under consideration. These maps are prepared with geographical data input, storage, process and analysis of the output. In other words, standard maps can be drawn as the output of the data processing based on GIS (Malczewski, 1999).

- Depth to water table: The distance between the earth surface and level of the ground water determines the depth of impact, i.e. it determines the thickness of the non-saturated section. The higher the depth to water table is, the more time it takes the materials to reach the ground water with the possibility of distribution, dilution and absorption of contaminants by soil. Data of the water level in piezometers of the Plain were used to prepare the map of the depth to water table. To this end, a table was primarily prepared of the water level information including the name of piezometers, situation of piezometers based on UTM and depth of the water in the statistical period between 2007-08 and 2008-09 in Excel domain. The information was then changed into a format acceptable for (*.xls) Arc GIS software. Internal detection through IDW was then used as a suitable method to change the mentioned spot data into the level. In this way the coaxial map of the depth to water table was prepared to be combined with other classes and was classified and rated based on the table 1. The rating map of the depth to water table which has been used in DRASTIC model of Gulgir Plain is shown in fig. 2-a.

- Net Recharge: The recharge of the ground water causes the contaminants to transfer vertically, reach the water table, and move along the aquifer horizontally. The DRASTIC model presumes that the main recharge sources are rain and snow falls. In order to examine the volume of the ground water reserve of Gulgir Plain, the overlap method of the map of balance changes of water table and map of distribution of reserve capacity of the ground water were used. In the method of water balance fluctuations of the ground water a direct estimation of the recharge is resulted by multiplication of the amount of the rise of stagnant water level by a special yield (Rushton, 2003). The method in based on the hypothesis that the rise of the balance of water level in unbounded subterranean water is the result of the ground water recharge. The amount of rise of the ground water due to this method is proportionate to the recharge through the soil surface. To this end, the unit hydrograph of Gulgir Plain drawn by specifying the wet season (maximum water table balance) and dry season (minimum water table balance) and the co-balance map of the water table was prepared for the wet and dry seasons. The data resulting from the model of ground water current of the Plain (Khuzestan Water and Electricity Company, 2006-07) was used to prepare the argillous layer of reserve capacity. Then the amount of recharge was calculated according to the relation 2 (Scanlon et al, 2002) by multiplication of map resulting from subtraction of minimum balance from maximum balance by the reserve capacity map and rated based on the rating table 1(Fig. 2-b).

$$R = S_y \, dh / dt = S_y \Delta h / \Delta t \qquad (2)$$

Where **R** is the rate of recharge, **Sy** is special yield, **h** is the water balance height and **t** stands for time.

- Aquifer media: The layer of the aquifer media is a descriptive layer which depends on the materials forming this aquifer. The aquifer media and the materials forming it determine the process of movement in the current system of the ground water. In order to prepare the layer of the ground water of Gulgir Plain the log of the observation-exploration wells was used. To prepare the layer of the aquifer media on the basis of the ratio of the forming materials a numerical value between 1 and 10 was allocated to each well (form the water table to the bed rock) based on the table 1. The rated map of the aquifer media was then prepared (Fig.2-c).

- Soil media: This section includes the upper part of the non-saturated area which extends up to the level of penetration of the roots of plants or activity of microorganism. The soil texture is used as a factor affecting the contamination potentiality in the DRASTIC model. The soil map of the region has been prepared based on the report of semi-detailed pedological studies of the lands of Gulgir region of Masjed Soleiman, plan of supply and transfer of water and pressured irrigation (state Water and Soil Engineering Service Company, Management of Karkheh Studies 2009-10). On this basis, upon determination of the sampling spots and identification of various types of soil in the region, the soil layer of the region was taken and stored as an argillous layer and was eventually rated based on the table 1 (Fig. 2-d).

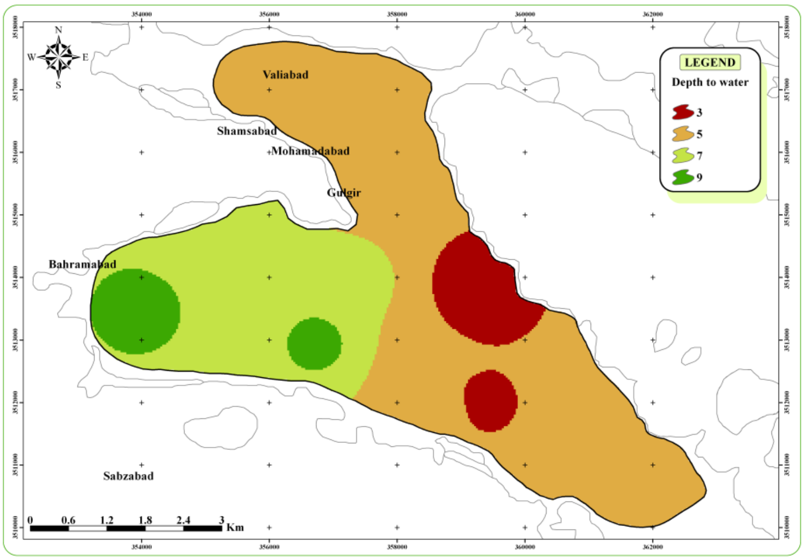
- Topography: A rise in the topography slope causes reduction of endurance of water on the earth surface and reduction of the penetration rate. A mild slope causes the rise of penetration rate leading to a higher contamination potentiality. The elevation-numerical files 1:25000 of the State Surveying Organization were used to prepare the slope map. These files contain baselines, elevated points and waterways. The elevation-numerical model of the region was prepared by using these factors. The DEM achieved by editing in the Arc GIS domain, in Spatial Analyst section and by using the Analysis Surface function the slope map of the region was achieved. The topographic layer of the region was then prepared based on the slope rates of the DRASTIC model in table 1. (Fig. 2-e).

- Impact of vadoze zone: The non-saturated region includes the existing residues from the water table to the soil zone. This area is non-saturated or alternatively saturated. The log of the observation - exploration wells and a method similar to the layer of the aquifer media were used to prepare this layer with the difference that the thickness and material of the upper layers of the stagnant water level are included in the log of the afore-mentioned wells (Fig. 2-f).

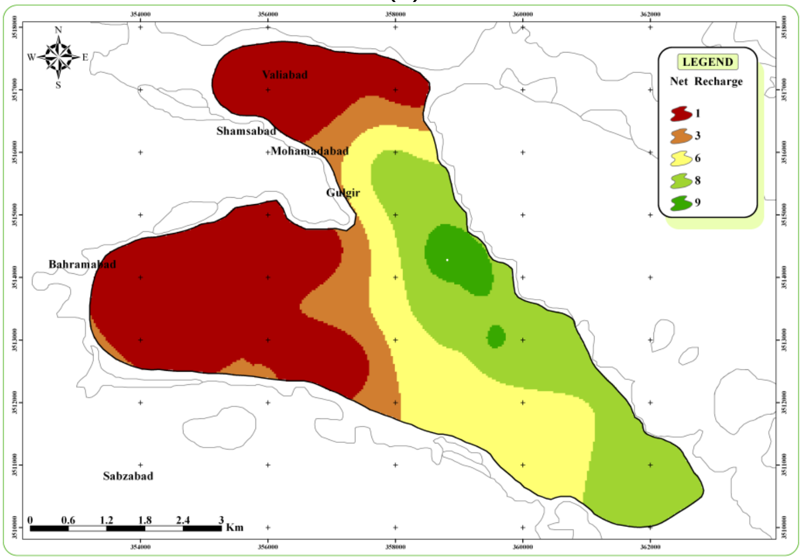
- Hydraulic conductivity: The hydraulic conductivity depends on the material of the soil, the intermediary zone and the aquifer. This parameter implies the capacity of water conduction and the contaminations solved in it. The higher the hydraulic conductivity is the lower the contamination mortality would be. The maps of transfer capacity and thickness of the ground water are required for preparation of the hydraulic conductivity layer. The map of hydraulic conductivity was prepared through dividing the transfer capacity layer to the thickness of alluvium, and rated based on table 1. In this way the hydraulic conductivity layer was achieved in order to be combined with other layers (Fig. 2-g)

Table 1. Classification and rating of parameters of DRASTIC model in the Gulgir plain

Rating	*Parametr*	*Rating*	*Parametr*	*Rating*	*Parametr*
	Topography (%)		*Net Recharge (Cm/Year)*		*Depth to water (m)*
10	*0 – 2*	*1*	*1.11 - 4.4*	*9*	***2.6 – 4.5***
9	*2 - 6*	*3*	*4.4 - 7.6*	*7*	*4.5 – 9*
5	*6 - 12*	*6*	*7.6 - 10.9*	*5*	*9 – 15*
3	*12 - 13*	*9*	*10.9 - 14.1*	*3*	*15 – 19.8*
		8	*14.1 - 16.56*		
Rating	*Hydraulic conductivity(m/d)*	***Rating***	*Impact of Vadoze zone*	***Rating***	*Aquifer media*
1	*7.7 – 8.6*	*9*	*Gravel with Sand*	*10*	*Gravel*
2	*8.6 – 9.49*	*7*	*Limestone*	*9*	*Gravel with Sand*
4	*9.49 – 10.39*	*7*	*Silt with Sand & fine Gravel*	*8*	*Clay with Sand & fine Gravel*
6	*10.39 – 11.28*	*6*	*Silt with interbed of Sand*	*8*	*Sand*
8	*11.28 – 12.18*	*6*	*Debrise Limestone & fine Sand*	*7*	*Silt with Sand & fine Gravel*
10	*12.18 – 13.07*	*5*	*Marl & Limestone*	*7*	*Limestone*
		5	*Silty Clay with Sand*	*7*	*Silt and Pebble*
Rating	*Soil media*	*5*	*Clay with Sand*	*6*	*Clay with Gravel*
10	*Silty Loam*	*4*	*Silt*	*6*	*Silt with interbed of Sand*
8	*Loam*	*3*	*Silty Clay*	*6*	*Debrise Limestone & fine Sand*
6	*Clay Loam*	*2*	*Marl*	*5*	*Silt*
4	*Silty Clay Loam*	*2*	*Clay with Silt*	*5*	*Silty Clay with Sand*
2	*Silty Clay*			*5*	*Marl & Limestone*
				4	*Clay with Sand*
				3	*Silty Clay*
				2	*Clay with Silt*
				2	*Marl*
				1	*Clay*



(a)



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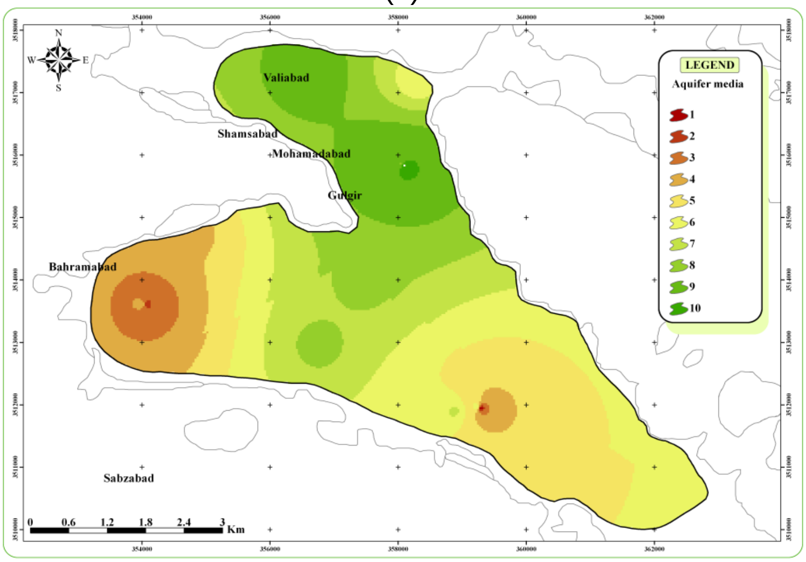
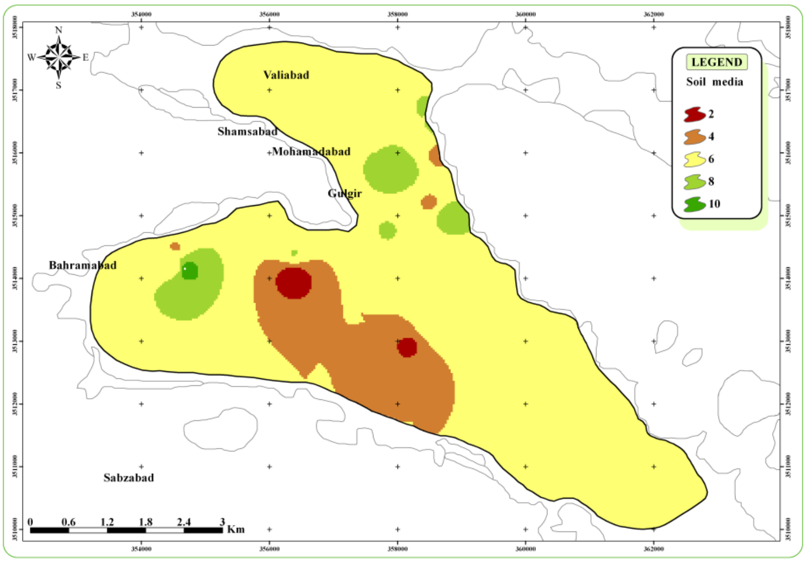


(c)

Fig. 2. Map of layers of DRASTIC model (**a**-Depth to water table, **b**- Net Recharge, **c**- Aquifer media, **d**- Soil media, **e**- Topography, **f**- Impact of vadoze zone, **g**- Hydraulic conductivity)



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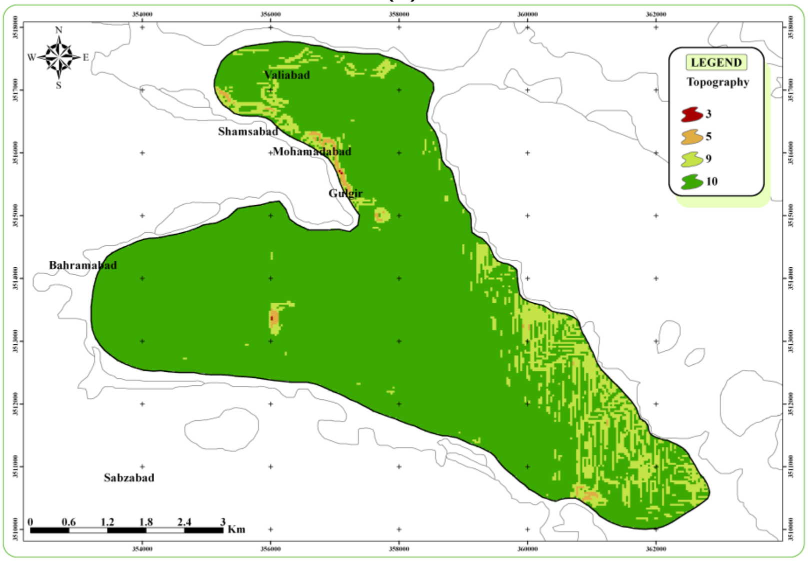

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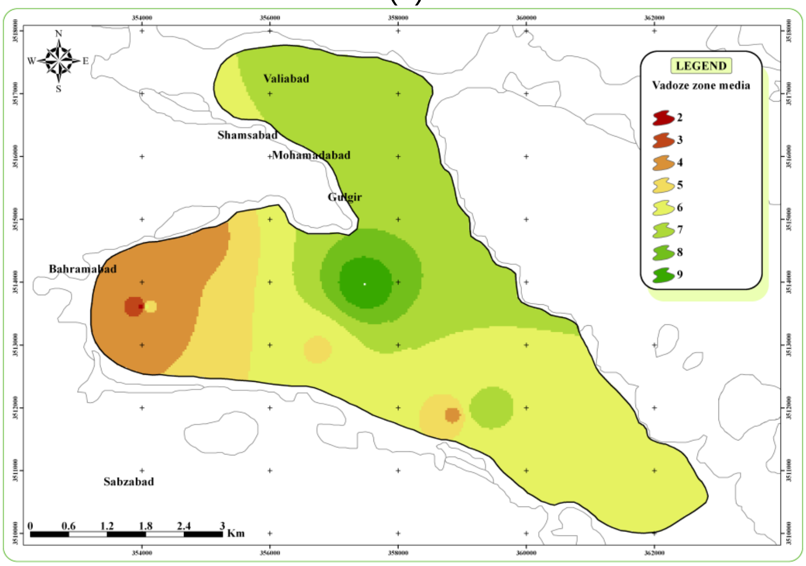

(f)

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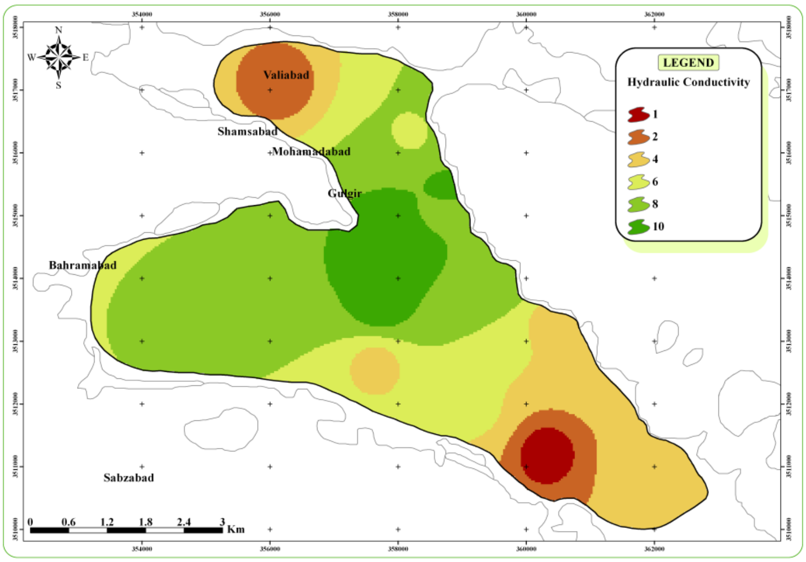


(g)

The continue of **fig. 2.**

Fuzzy Model

Evaluation of the vulnerability of ground water or description of contaminated areas is not an easy task since it depends on many complicated parameters. The lack of certainty and assurance is innate to all methods of evaluation of vulnerability which is the result of information error and variability of the hydro-geological parameters to the time and place (Anonymous, 1993). Therefore, preparation of a flexible model that can respond in an uncertain condition with the least entries is a proper managerial tool for evaluation of vulnerability of the subterranean water. Use of fuzzy logic has become highly widespread in many scientific branches which need information classification. Whereas classification of information in evaluation of the vulnerability of the ground water and determination of the border between these classifications are of particular importance, the fuzzy logic would evaluate the vulnerability better than common methods (Dixon et. el, 2002). Stages of making a fuzzy control system is generally expressed as follows (Fig. 3):

1 - Fuzzifier the definite values of the entries
2 - Extracting the rules base and method of fuzzy deduction
3 - Defuzzifier the output fuzzied values.

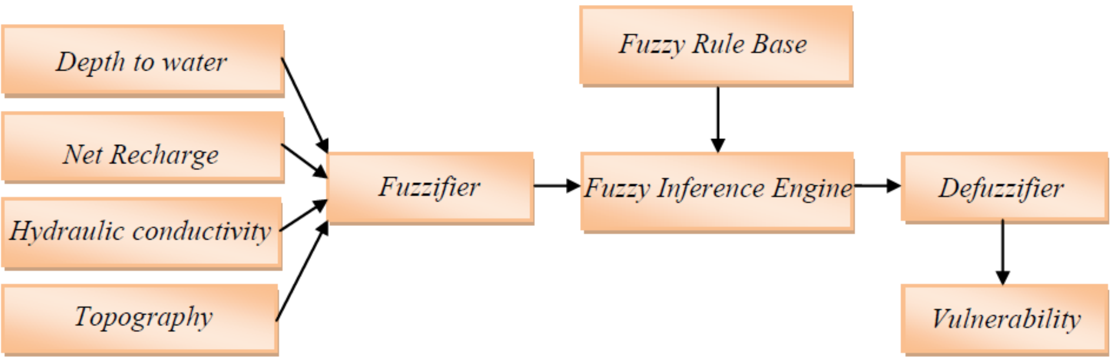


Fig. 3. Structure of fuzzy model for vulnerability evaluation

To fuzzy the definite entry values: The first step in establishing a fuzzy model is to define the inputs and membership functions. The input parameters of fuzzy deduction model include depth to water table, net recharge, topography and hydraulic conductivity. There is no possibility to make a fuzzy deduction for other three parameters of the DRASTIC model, namely aquifer media, vadoze zone media and the soil media because they lack moderate values. The aforementioned parameters have become fuzzy using of Gaussian membership function. The fuzzy chart of each parameter was drawn by programming in MATLAB software domain. Whereas the parameters are independent they would have separate fuzzy. For the variables of depth to water table, amount of net recharge and Hydraulic conductivity membership functions such as very high, high, moderate, low and very low have been defined. For the topography variable the membership functions of high, moderate, low and very low have been considered (Fig. 4).

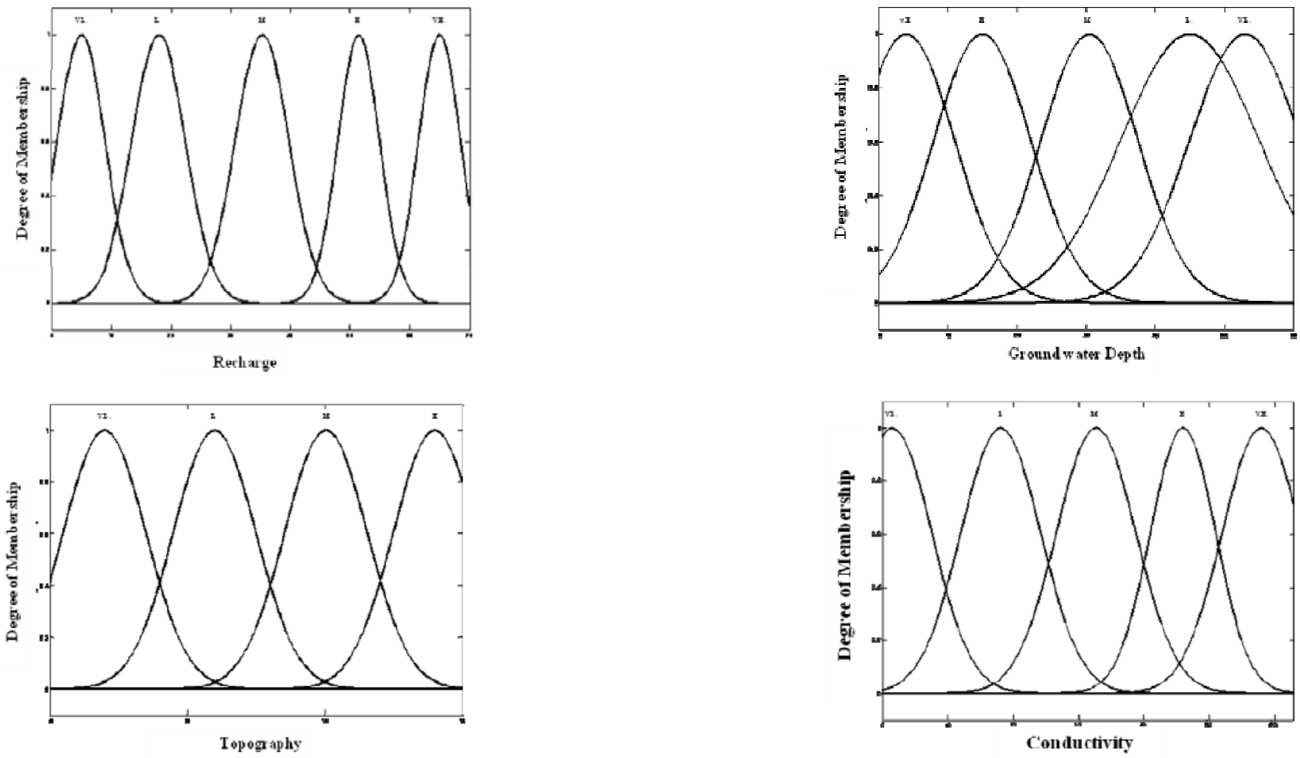


Fig. 4. Input membership functions of fuzzy model

The extent of membership in these charts is achieved from relation 3:

$$f = (x; \delta, c) = e^{\frac{-(x-c)^2}{2\delta^2}} \tag{3}$$

Where **c** is the average or center of the Gaussian curve, **δ** is deviation of criterion of membership function and **x** is the value of the parameters. The value of these parameters for the membership functions of the fuzzy model is as follows:

$c = [2,2,2,2,2.5]$ $\delta = [5.5,9.96,16.5,22,27]$ Depth to water table **-**

$c = [1.5,1.5,1.5,1.5,1.5]$ $\delta = [3.5,7.10.5,14,17.5]$ Net Recharge **-**

$c = [4,4,4,4,4]$ $\delta = [2,8,15,22,28]$ Hydraulic conductivity **-**

$c = [1,1,1,1]$ $\delta = [4,8,14,18]$ Topography **-**

Extraction of rules base and fuzzy deduction method: After fuzzify the input parameters; the fuzzy rules base is made. The fuzzy rules evaluates the vulnerability through fuzzy phrases consisting of "If -.then" and in each rule the combined effects of the used indexes are determined in terms of the intended viewpoint. The number of the required rules depends on the number of indexes and number of classes of each index which is calculated on the basis of relation 4.

$$I = K_1 \times K_2 \times \ldots\ldots \times K_n \qquad (4)$$

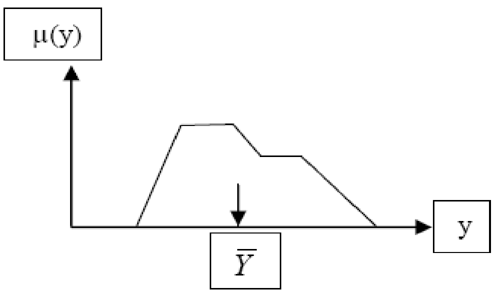
Where **I** am the number of rules, **n** is the number of index and **K** is the number of classes in each index. In this research and based on this relation 500 rules may be defined in view of the number of variables and the classes thereof however, 100 rules have been defined based on the studies (table 2).
One membership function is created for the output of each existing rule in view of Mamdani fuzzy Inference method. In this method which is used for conjunctive rules, the lowest membership degree is chosen from the membership degrees of the inputs of a fuzzy rule in each range and transferred to the output. This is repeated for all the rules in all the ranges of changes in the variables in order to achieve the output fuzzy variable.

Non - fuzzying the output fuzzy values: Output fuzzy values should be changed into the actual number by using the defuzzifier method and based on the output membership function. There are different methods for non - fuzzying the output. These may include height, average, maximum, Center of gravity, the present research has used the defuzzifier Center of gravity method to calculate the actual value of the output index. This is the most common method for changing the fuzzy quantity into the classic quantity. To calculate the value, the relation 5 has been used (Teshnehlab et al., 2009).

$$\overline{Y} = \frac{\int y\mu(y)dy}{\int \mu(y)dy} \qquad (5)$$

Where **y** is the output quantity, **μ(y)** is the output membership grade of y and **Ȳ** is the actual quantity of the output.

Fig. 5. Center of gravity Defuzzifier



Evaluation of vulnerability of aquifer

Results of the DRASTIC model (Fig. 6-a) show that the highest rate of vulnerability is observed in the eastern part of Gulgir Plain. The high rate of recharge, large granulation of the aquifer, vadoze zone media, soil media and hydraulic conductivity seem to be involved in the high rate of vulnerability in this part of the Plain. The lowest rate of vulnerability is seen in the northern, western, northwestern and southwestern parts of the Plain. On this basis 15.54 % of the Plain has a very high vulnerability, 39.25 % has a high vulnerability and 45.21 % has a moderate vulnerability. The result of the fuzzy deduction system (Fig. 6-b) also confirms that the eastern part of the Plain has the highest rate of vulnerability. This area enjoys the highest rate of feeding. On this basis, 4.69 sq. kilometers (15.36 %) of the Plain has a very high rate of vulnerability, 2.32 sq. kilometers (7.58 %) has a high rate of vulnerability, and 23.56 sq. kilometers (77.05 %) has a medium rate of vulnerability. Based on this method an extensive part of the Plain would be moderately vulnerable

Table 2. Rules base of fuzzy model of vulnerability

Row	Depth to water	Net Recharge	Hydraulic conductivity	Topography	Vulnerability
1	V.L.	V.H.	M.	H.	M.
2	V.L.	H.	H.	M.	L.
3	V.L.	M.	H.	L.	V.L.
4	L.	V.H.	M.	L.	L.
5	M.	V.H.	M.	M.	H.
6	M.	V.H.	L.	L.	M.
7	H.	H.	M.	L.	H.
8	H.	H.	M.	M.	H.
9	H.	L.	L.	V.L.	L.
10	H.	L.	M.	L.	M.
11	M.	L.	V.H.	V.L.	M.
12	M.	V.L.	H.	V.L.	M.
13	H.	V.L.	L.	V.L.	M.
14	V.H.	H.	M.	L.	H.
15	V.H.	M.	M.	V.L.	H.
16	V.H.	L.	M.	V.L.	M.
17	V.H.	V.L.	L.	V.L.	L.
18	V.H.	L.	L.	L.	L.
19	V.H.	V.L.	M.	V.L.	M.
20	H.	V.L.	V.L.	H.	L.
21	H.	L.	V.L.	M.	L.
22	M.	V.L.	V.L.	L.	V.L.
23	M.	V.L.	M.	V.L.	L.
24	M.	V.L.	L.	L.	L.
25	H.	L.	V.L.	M.	L.
26	H.	L.	V.L.	H.	L.
27	M.	L.	L.	M.	V.L.
28	L.	L.	L.	L.	V.L.
29	L.	M.	L.	H.	V.L.
30	L.	M.	L.	L.	L.
31	L.	L.	V.L.	M.	V.L.
32	M.	M.	M.	V.L.	M.
33	M.	H.	M.	L.	M.
34	H.	H.	L.	L.	H.
35	H.	M.	L.	L.	H.
36	H.	L.	L.	L.	M.
37	M.	V.L.	V.H.	V.L.	M.
38	M.	L.	H.	V.L.	M.
39	H.	V.H.	M.	M.	V.H.
40	H.	H.	M.	M.	H.
41	L.	V.H.	H.	H.	M.
42	L.	V.H.	H.	M.	M.
43	L.	H.	H.	L.	M.
44	L.	H.	M.	L.	M.
45	H.	V.H.	H.	L.	V.H.
46	M.	V.H.	M.	V.L.	H.
47	V.L.	M.	H.	M.	L.
48	V.L.	H.	H.	L.	L.
49	L.	V.H.	H.	L.	M.
50	M.	V.H.	H.	V.L.	H.
51	M.	V.H.	H.	H.	V.H.
52	L.	V.H.	H.	M.	V.H.
53	V.L.	M.	H.	H.	M.
54	V.L.	H.	M.	H.	L.
55	V.L.	M.	M.	V.L.	M.
56	V.L.	H.	M.	L.	L.
57	V.L.	M.	H.	V.L.	L.
58	V.L.	H.	M.	M.	L.
59	V.L.	M.	M.	H.	L.
60	L.	H.	M.	H.	V.L.
61	L.	M.	H.	M.	V.L.
62	L.	L.	M.	L.	V.L.
63	L.	M.	M.	H.	V.L.
64	M.	H.	M.	H.	L.
65	M.	M.	H.	H.	L.
66	M.	M.	M.	L.	M.
67	M.	M.	V.H.	H.	M.
68	L.	H.	M.	M.	L.
69	L.	M.	H.	L.	V.L.
70	L.	L.	L.	H.	V.L.
71	V.L.	L.	M.	M.	V.L.
72	V.L.	M.	L.	H.	V.L.
73	L.	V.L.	M.	H.	V.L.
74	V.L.	L.	L.	H.	V.L.
75	H.	L.	M.	L.	H.
76	V.H.	M.	L.	V.L.	H.
77	V.H.	H.	H.	M.	V.H.
78	V.H.	H.	M.	L.	V.H.
79	H.	M.	H.	V.L.	H.
80	H.	H.	M.	L.	H.
81	H.	V.H.	H.	L.	V.H.
82	H.	H.	M.	L.	H.
83	H.	L.	H.	L.	M.
84	H.	M.	M.	M.	M.
85	M.	H.	H.	L.	M.
86	H.	M.	M.	V.L.	H.
87	V.H.	M.	H.	M.	H.
88	V.L.	L.	M.	H.	V.L.
89	V.L.	V.L.	H.	L.	V.L.
90	V.L.	M.	M.	H.	V.L.
91	V.L.	M.	M.	M.	V.L.
92	V.L.	L.	L.	V.L.	V.L.
93	V.L.	L.	V.L.	L.	V.L.
94	V.L.	M.	L.	V.L.	V.L.
95	V.L.	M.	H.	V.L.	L.
96	V.L.	L.	V.L.	H.	V.L.
97	V.L.	L.	L.	V.L.	V.L.
98	V.L.	M.	V.L.	V.L.	V.L.
99	M.	V.L.	V.L.	L.	V.L.
100	M.	M.	V.L.	L.	M.

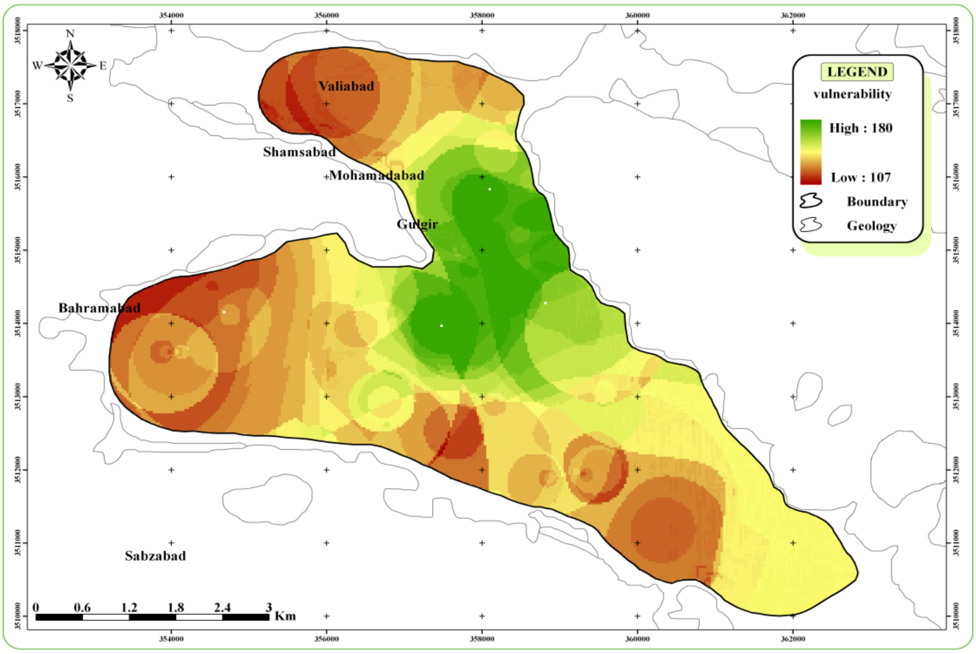
« Very Low: V.L. ‹Low : L. ‹Moderate : M. ‹ high : H. ‹Very high :V.H.»

Verification of the model

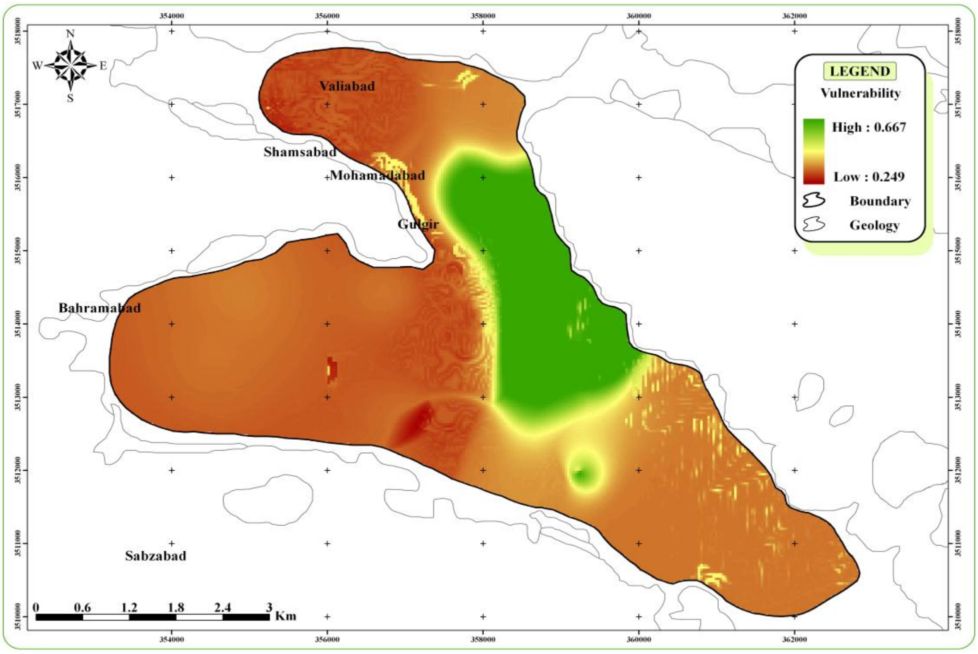
In order to verify the results of the model regarding the nitrate density, data samples taken from the water well in March 2006 were used. Presence of nitrate in the subterranean water implies the destruction of the water quality. Due to the use of fertilizers, in the region which is mainly manures or nitrated chemical fertilizers the nitrate ion existing in the ground water is analyzed.

Based on the nitrate coaxial map (Fig. 7), the volume of nitrate in the ground water is higher in the eastern and northern parts than other parts of the Plain.

In order to specify the parameter with the highest effect on vulnerability of the ground water in the Gulgir plain, the correlative coefficient between the parameters of the DRASTIC model and the nitrate layer was calculated (table 3). The results show that net recharge has the most correlation with the nitrate layer and therefore it has a higher impact on the vulnerability of the subterranean water as compared to other parameters of the DRASTIC model, followed by hydraulic conductivity, aquifer media and vadoze zone media.



(a)



(b)

Fig. 6. The vulnerability map of Gulgir Plain (**a**. DRASTIC model, **b**. fuzzy model)

Table 3. Correlation between layers of DRASTIC model and nitrate density

Hydraulic conductivity	Vadoze zone media	Topography	Soil media	Aquifer media	Net Recharge	Depth to water	Layers
0.3881	**0.2791**	**0.2081**	**0.2737**	**0.3145**	**0.5138**	**0.2236**	Nitrate

Conclusion

Results of the present research generally show that the general trend of vulnerability is the same in using the definite and fuzzy layers. However, when the fuzzy layers are used, the gradual mode of change appears more clearly. Whereas layers are combined through Boolean logic in the DRASTIC method, errors emerge in border values and a slight change in the quantity of the factors causes relocation from one class to another which is not justifiable. Therefore, use of the fuzzy logic improves the accuracy of the results particularly concerning the border values.

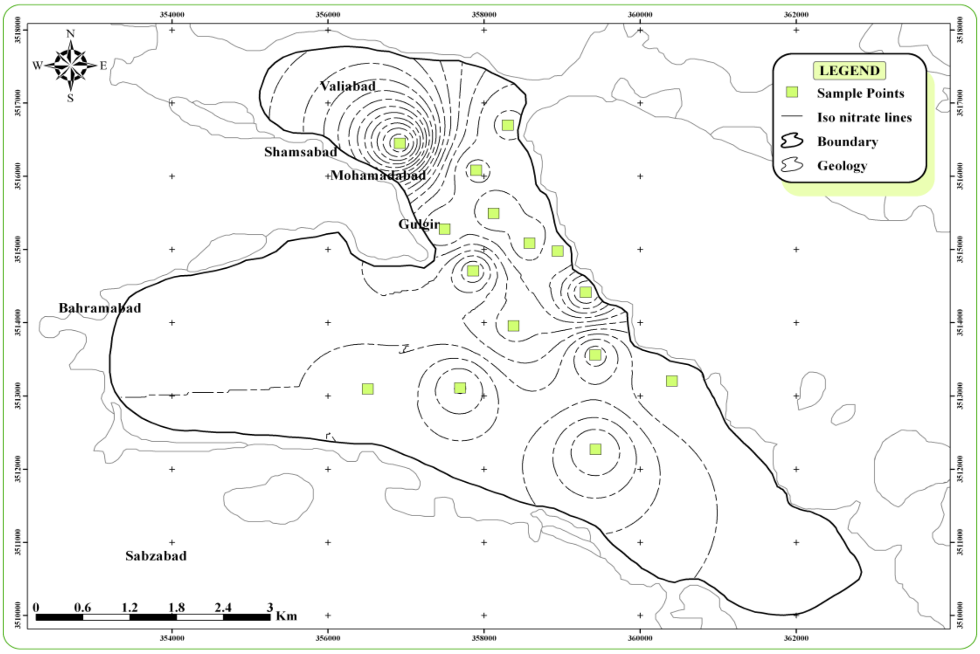


Fig. 7. Coaxial nitrate map in subterranean water of Gulgir Plain

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