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Evaluation of Meymeh Aquifer vulnerability to nitrate pollution by GIS and statistical methods

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Abstract. Increasing the concentration of nitrate ions in the soil solution and then leaching it to underground aquifers increases the concentration of nitrate in the water, and can cause many health and ecological problems. This study was conducted to evaluate the vulnerability of Meymeh aquifer to nitrate pollution. In this research, sampling of 10 wells was performed according to standard sampling principles and analyzed in the laboratory by spectrophotometric method, then; the nitrate concentration zonation map was drawn by using intermediate models. In the drastic model, the effective parameters for assessing the vulnerability of groundwater aquifers, including the depth of ground water, pure feeding, aquifer environment, soil type, topography slope, non-saturated area and hydraulic conductivity. Which were prepared in the form of seven layers in the ARC GIS software, and by weighting and ranking and integrating these seven layers, the final map of groundwater vulnerability to contamination was prepared. Drastic index estimated for the region between 75-128. For verification of the model, nitrate concentration data in groundwater of the region were used, which showed a relative correlation between the concentration of nitrate and the prepared version of the model. A combination of two vulnerability map and nitrate concentration zonation was provided a qualitative aquifer classification map. According to this map, most of the study areas are within safe and low risk, and only a small portion of the Meymeh Aquifer, which has a nitrate concentration of more than 50 mg / L in groundwater, is classified in a hazardous area.

Keywords: nitrate contamination; GIS; Meymeh aquifer; drastic model

1. Introduction

Groundwater is the most important source of freshwater on Earth (Villeneuve *et al.* 1990), In general, the quality of groundwater, especially in agricultural active areas, which is used from agricultural and animal fertilizers, is under the potential of contamination (Lake *et al.* 2008. Chae *et al.* 2003, Almasri 2004).

One of the ways to prevent groundwater contamination is to identify areas with high contamination potential, and by this recognition, the region can be zoned in terms of vulnerability, and as a result prevented the application of necessary measures to infect areas with high vulnerability (Asghari Moghadam *et al.* 2009),

Considering the importance of the issue of aquifer vulnerability and the assessment of the ability of various methods and patterns in this regard, various studies have been carried out all over the world. Iuliana Gabriela Breaban, Madalina Paiu in 2012 in the study of the use of the drastic and GIS model, was evaluated on the vulnerability of the Barklad Aquifer. Khazaei, *et al.* in 2011, was investigated the zonation of nitrate pollution in underground waters of the Syakh Darengon area in Fars province. Afrouzi *et al.* in 2013, was investigated the vulnerability of the Borujen aquifer by drastic method, and calibration of the pattern by using nitrate concentration in the observation wells of the area. Amirahmadi, in 2013, in the study of vulnerability of Neishabour plain aquifer using the drastic method in the GIS interface media with nitrate ion adaptation on the final drastic map, determined that all points with high nitrate levels are in high contamination, which validates the accuracy of the model. Neshat *et al.* was investigated Vulnerability of agricultural aquifers in Kerman, their calibration results using Wilcoxon's nonparametric test, and nitrate concentrations with a correlation coefficient of 82% was raised. Victor Rodrigues, in 2014, in analyzing the amount of nitrate using the random forest variables algorithm and the method of reducing the number of variables, and RF algorithm, was evaluate the vulnerability of groundwater in the southern regions of Spain. The results showed high regression and the ability of the recurrence network to predict the concentration in the aquifer. Lasagna *et al.* 2016, the Role of Physical and Biological Processes in Aquifers and Their Importance in the vulnerability of groundwater, they examined nitrate pollution in northwest Italy and considered dilution as the most important factor in nitrate removal.

Goodarzi *et al.* 2017, in a study to assess the vulnerability of groundwater to nitrate pollution they examined agricultural activities in Qazvin aquifer. Their results indicated that 9% of the aquifer is in the high risk

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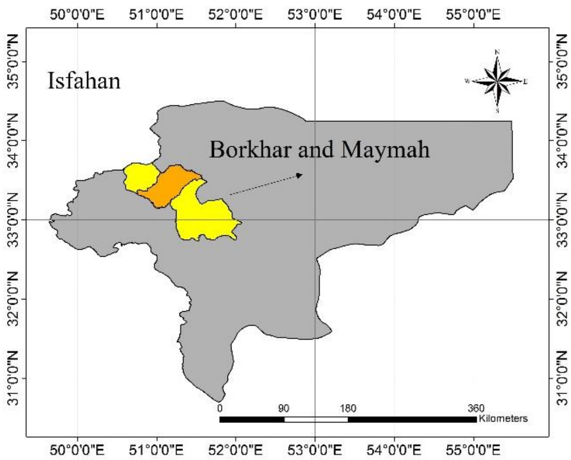


Fig. 1 Map of Meymeh geographical position

area Also; the soil environment factor has the greatest impact on aquifer vulnerability. Electrochemical reduction of nitrate was studied by Lee *et al.* (2018) using Zn, Cu and (Ir+Ru)-Ti cathodes and Pt/Ti anode in a cell divided by an ion exchange membrane. Chan *et al.* (2018) investigated the effect of Polyethylene Glycol (PEG) crosslinking in Polyvinylidene Fluoride (PVDF) in immobilization of Fe and bimetallic Fe/Cu and Cu/Fe zero valent particles on the membrane and its efficiency on removal of nitrate in wastewater.

In this research, sampling of 10 wells was performed according to standard sampling principles and analyzed in the laboratory by spectrophotometric method, then; the nitrate concentration zonation map was drawn by using intermediate models.

2. Study area

Meymeh region is one of the main areas of the Gavkhoni basin in Iran, located in the northwest of the basin. The area of this region is 2064.5 square kilometers. Study Range located between 50° 45′ E, to 51° 35′ E, and 33° 9′ N, to 33° 42 N. (figure 1).

3. Methodology

3.1 Drastic method

Drastic Model is the most commonly used over-the-over index model by the US Environmental Protection Agency (US-EPA) and American Wells Association (AWA) has been developed to determine the potential of groundwater contamination. This model is calculated using seven factors affecting the potential of groundwater contamination. These factors includes: Depth to water table (D), Net recharge (R), Aquifer media (A), Soil media (S), Topography (T), Impact of vadose zone media (I), Hydraulic conductivity of the aquifer (Aller *et al.* 1987), Accordingly, each factor with respect to its relative importance, comparison to other relative weight factors is between 1 and 5, and to each of these intervals ranks from 1 to 10. Use the following formula to determine the drastic index:

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

In this formula, W is weight and R is the rate associated with each of the parameters of the model. After calculating the Drastic Index, vulnerable aquifers are identified.

3.2 Investigating the status of nitrate in aquifer

Nitrate is considered as the last stage of oxidation of nitrogen compounds, which is the cause of methemoglobulinemia in infants**,** and the probable formation of carcinogenic nitrosamine compounds as one of the chemical indices of water pollution in sewage is considered (Abedi 2001),

In the Meymeh range, no systematic sampling has been carried out, based on specific standards for nitrate contamination. In this research, considering the equipment and facilities of the university, it is possible to examine the vulnerability by sampling, analyzing and interpreting the results according to the required standards.

Simultaneously with the sampling and analysis process, it is possible to run the drastic model and then calibrate the model with existing samples and provides a precise map of the aquifer’s vulnerability According to the studies, the drastic model is the best model for assessing the vulnerability of aquifers. In order to study nitrate pollution, sampling of 10 deep and semi-deep wells with appropriate dispersion in the region was carried out in accordance with the principles of National Standard Sampling No. 1053 of the Institute of Standard and Industrial Research of Iran in the summer of 1395, and was sent to the hydrologic laboratory under temperature and time conditions and analyzed by Spectrophotometer.

4. Results and Discussion

4.1 Depth of water

Groundwater depth is one of the important factors in controlling the ability of pollutants to reach the aquifer. This determines the depth of the pollutant to reach the water table and is important (Asghari moghadam *et al.* 2009. Khodaei *et al.* 2006), The depth of the water table was determined by interpolation of the points obtained from the mean depth of the water table of the piezometers for an eight year period (2003-2011) in the Arc GIS environment using the IDW method (Table 1)

As shown in Fig. 2, the depth of impact on the water table varies from 13 to 89 meters from the ground. The minimum depth is related to parts in the west and east of the region and the highest depth is related to the center, north and south. This layer is placed in 4 classes (1, 2, 3, and 5),

4.2 Net recharge

Net recharge is a very important factor for the penetration and transfer of pollutants from the non-saturated area to the saturated area, and transfer solid and liquid pollutants into the surface of water and also can increase the water level (Rahman 2008),

Piscopo method (2001) was used to prepare the nutrient layer. The Piscopo equation is as follows:

Soil permeability score + rainfall score + slope percentage score = nutrition score

To prepare the permeability map by reference to drilling log for piezometric wells in the Meymeh Aquifer (Regional Water Organization of Isfahan Province), the weight percent of each component of the aquifer, such as clay, silt, sand, granule and gravel, is calculated, Finally, considering the permeability coefficient of each of them, the aquifer's average permeability coefficient is calculated in wells and adjacent areas. Finally, the aquifer penetration map was classified according to the criteria in Table 1.

Figure 2 shows the net nutrition of the Meymeh aquifer. Based on the Piscopo method, a maximum score of 5 and a minimum score of 3 were obtained for the nutrition index, and the major part of the region has a rank of 5. So, much of the study area has a moderate speed for transmitting pollutants to groundwater levels and there is a potential for transfer of pollutants to groundwater.

4.3 Aquifer media

For the aquifer layout, log piezometers and logs of exploratory wells, the type and gender of the aquifer environment were identified (Isfahan regional water company 2009). In this way, according to the ratio of the material of the aquifer forming material in each well, the rankings according to Table 1 were allocated to each point. Then the polygons related to the aquifer map were prepared by GIS software and the mapping of the aquifer environment was prepared by Raster format (National Surveying Organization 2007),

According to Figure 2, the aquifer environment has a score of 7 (sand, granule, clay) and a very low score of 8 (sand and granule) and 9 (gravel, granule, sand and clay), Therefore, due to the fact that the aquifer environment is roughly coarse, the flow of pollutants in the groundwater aquifer system increases.

4.4 Soil media

Soil layer became according to the information obtained from the Land Resources Assessment Map (provided by the technical deputy of the Natural Resources and Watershed Management Office of Isfahan, according to the information of the Soil and Water Institute), as well as the information of the observation wells and Expert Opinions, polygons were then determined using GIS software as Raster, based on the Drastic method and Table 1.

According to Fig. 2, the major part of the region has a silty loam texture (score 7), followed by loamy sand (score 8), The presence of materials with a fine texture such as silt reduces the ability to transfer pollutants from the soil to the groundwater system.

4.5 Topography

In order to obtain a slope layer, maps of 25000/1 were used and were calculated according to Table 1. According to

Table 1 Ranking and weighing of seven factors affecting the potential of groundwater contamination

Nutrition rate		**Soil permeability**		**Rain**		**Slop**	
Factor	Range	Factor	Range	Factor	Rain	Factor	Slop (Percent)
5	7-8	5	high				
		4	Medium to high			4	<2
		3	Medium to low	1	< 500		
3	5-7	2				3	2-10
		1	Very low				
Slop		**Soil**		**Aquifer Media**		**Water Level Depth**	
Rating	Range	Rating	Range	Rating	Range	Rating	Range(M)
10	0-2	4	Clay	7	Granule, sand and clay	5	15.1-13.89
9	2-6	5	Loam	8	Granule, sand	5	22.7-15.1
		6	Loam			2	30.4-22.7
5	6-9.4	7	Pit Loam Silt	9	Gravel, Granule, sand and clay	1	30.4
		8	Loam Sand				
Relative Weight:1		Relative Weight: 2		Relative Weight: 3		Relative Weight: 5	
				Hydraulic Conductivity		**Vadose Media**	
				Rating	Range	Rating	Range
				1	0.35-1.4	4	clay, sand and granule
				2	1.4-12.3		
				4	12.3-28.7	5	Granule, sand and clay
				6	28.7-49.43		
				Relative weight: 3		Relative Weight: 5	

Figure 2, the main part of the slope area is 0-2% (rank 10), Due to the low slope of the region, the time of contact of surface water and pollutants with the surface of the earth is increased and there is a greater chance of penetration, and this increases the pollution force in the area.

4.6 Impact of vadose zone media

Includes a part located between the water table and the soil environment, which is essentially unsaturated, or unbroken saturated. In order to prepare a non-saturated environment, the logs of wells in the area were used and ranked according to Table 1.

As shown in Fig. 2, the main part of the non-saturated Meymeh water aquifer is 6 (granule, clay sand), which covers the eastern, northern and southern parts, and the west of aquifer has a grade 4 (clay, granule and sand),

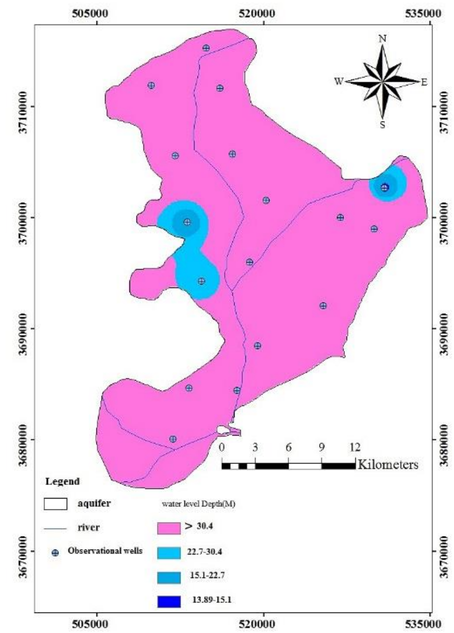
4.7 Hydraulic conductivity

Hydraulic conductivity information is derived from the calculations of the pumping test (Isfahan Regional Water Company 2010). Due to the fact that in the pumping experiments, the amount of the characteristic of the water transfer coefficient is calculated, using the aquifer saturation thickness, the hydraulic conductivity was obtained by dividing the coefficient of water transfer ability on the aquifer saturation thickness. (Equation 1), The amount and geographical points related to the ability coefficient of transmission and also the thickness of alluvial plain were obtained from available information and reports. Then, by using the Raster calculator function, the map of the thickness of saturation were obtained from the subtraction of the alluvium and the map of the depth of the water map were obtained from the mapping of the saturated thickness map, and after dividing the map of transmission capability on the map of the aquifer saturation thickness, the hydraulic conductivity map of the plain was obtained. The resulting map was scored according to Table 1.

$$k = \frac{T}{b}\left({}^{m}/_{day}\right) \quad (2)$$

where K is Hydraulic conductivity of aquifer in terms of (m/day), *T* is Water transfer coefficient in terms of (m2/day) and *b* is Saturation layer thickness in terms of (m),

Figure 2 shows that most of the aquifer has a hydraulic conductivity of 4.1-12.3 m / day, i.e., a score of 2, followed by a 4 (hydraulic conductivity of 28.7-12.3 m / day),



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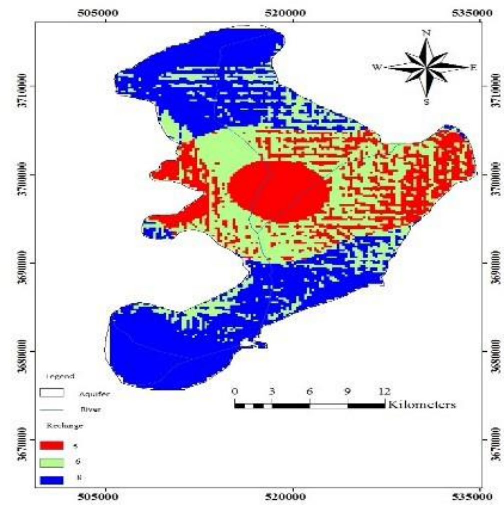

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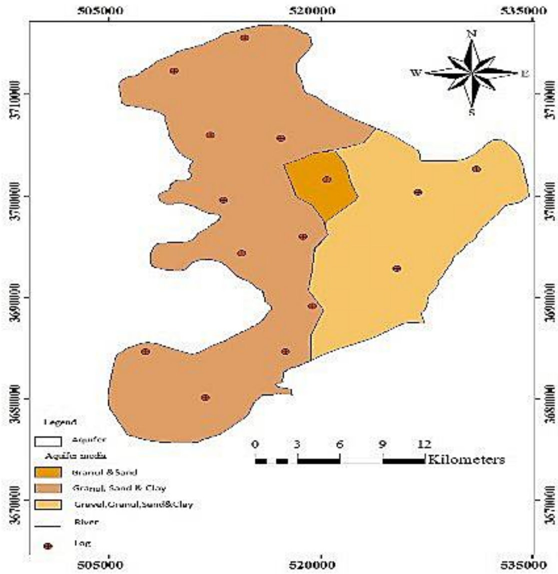

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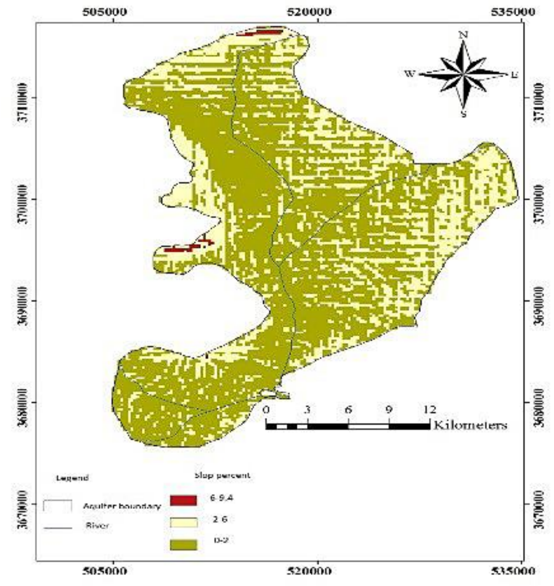

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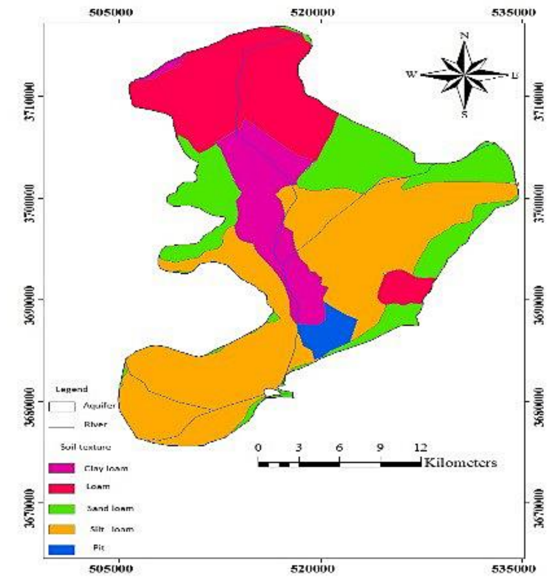

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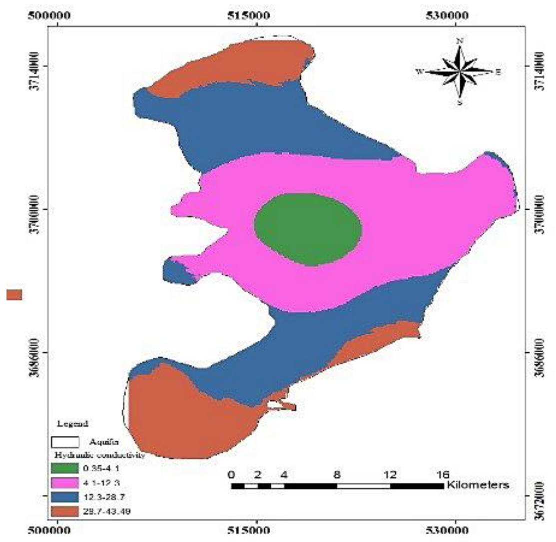

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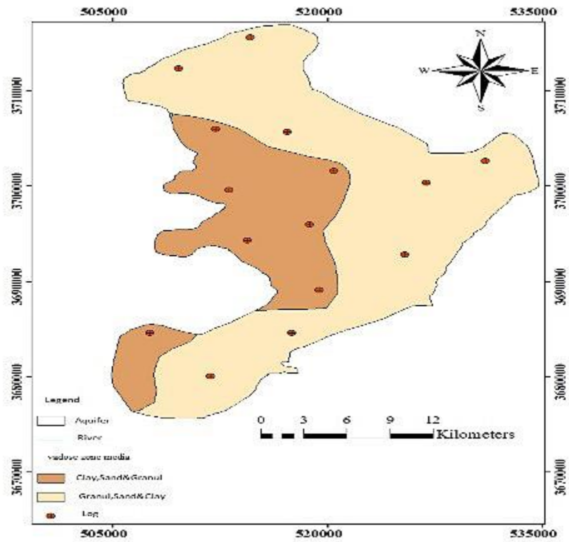

(g)

Fig. 2 Map of seven factors affecting the potential of groundwater contamination (a) Underground water depth zoning map (b) pure nutrition map (c) Aquifer media zoning map (d) topography (e) soil media zoning map (f) hydraulic conductivity zoning map (g) Vadose media zoning map

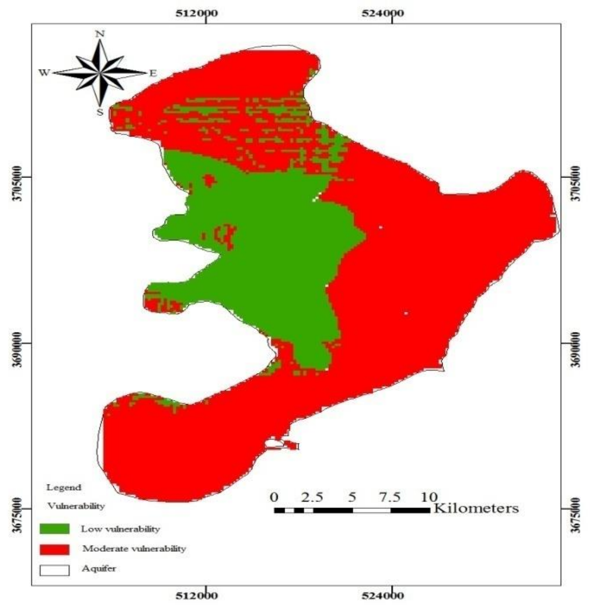

Fig. 3 Vulnerability zoning map by drastic method

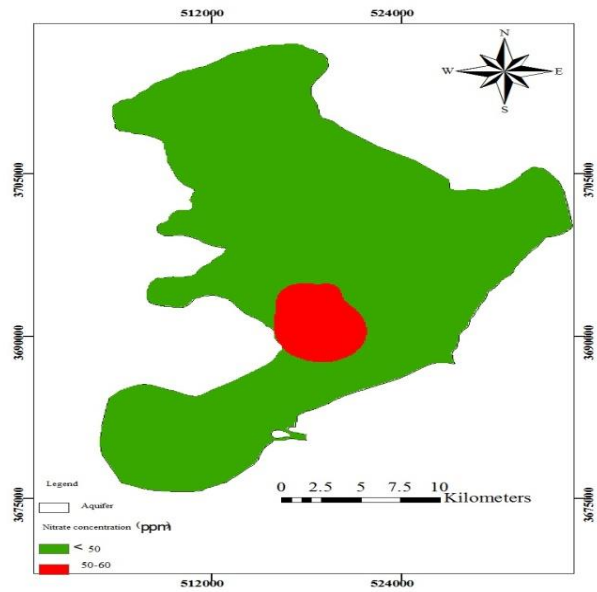

Fig. 4 Sampling wells position map

That is, the ability of the Meymeh aquifer components in many parts of the area to transmit water is relatively low and this will reduce the flow of pollutants and spread them in aquifers and reduce vulnerability. This is the case in the central, eastern and western parts of the aquifer.

After preparing seven layers related to the GIS drastic features, it is used to combine maps prepared using the Raster Calculator command in the Spatial Analyst toolbox. Using this raster calculator, each layer was multiplied by its coefficient and then all the layers were summed together. At the end, vulnerability zones were categorized based on this method.

The map for the Meymeh Aquifer regarding to drastic is shown in Fig. 3. In this method, the vulnerability is in the range of 75- 128 (low and moderate vulnerability).

4.8 Preparation of nitrate concentration map

According to the World Health Organization and the latest national standards of the country, the maximum permissible nitrate ion in drinking water is 50 mg / l in terms of nitrate. According to the experiments conducted in the study area, the average total sample was less than national and global standards, however, in some samples high concentration of standards were recorded.

According to table 2, the highest amount of nitrate in the sources is about well No. 8, 59.42 mg / l, and the lowest value for well No. 1 is 8.51 mg / l (Fig. 4), One of the main reasons for the high concentration of nitrate in the southern part of the aquifer is agricultural activities.

Using the two vulnerability maps (Fig. 3) and nitrate contamination in the region (Fig. 5), the quality of

Table 2 Sampling wells position and their concentration

10	9	8	7	6	5	4	3	2	1	Sample No.
Vazvan	Vandad	Esfahan	Saeid	Meil	Ghanat	Barghia	Taghot	Eng2	Enghelab1	Well name
519419	519350	518884	517744	514043	514255	515598	516194	516849	516682	X
3699249	3694192	3691006	3693623	3701791	3702566	3705598	3704523	3703863	3703126	Y
15.63	50.83	59.42	54.99	19.02	17.10	9.07	44.14	17.70	8.51	Nitrate Concentration Ppm

Table 3 Drastic vulnerability index rating & Original and corrected weights of drastic model

Corrected weight	Original weight	Spearman's Correlation coefficient	Parameter	Drastic Vulnerability Index	
-	5	-	D	Range	Rating
5	4	0.4	R	1-100	Low Vulnerability
3	3	0.24	A	101-140	Intermediate
---	2	-0.09	S	141-200	High
---	1	---	T	> 200	Very High
5	5	0.41	I		
5	3	0.4	C		

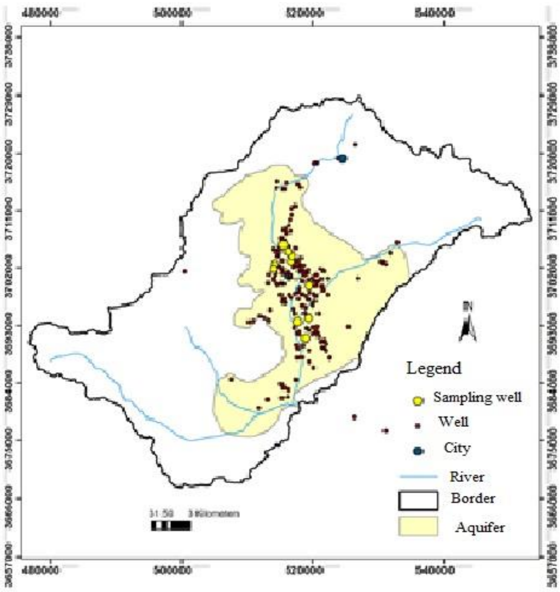

Fig. 5 Aquifer concentration zoning map

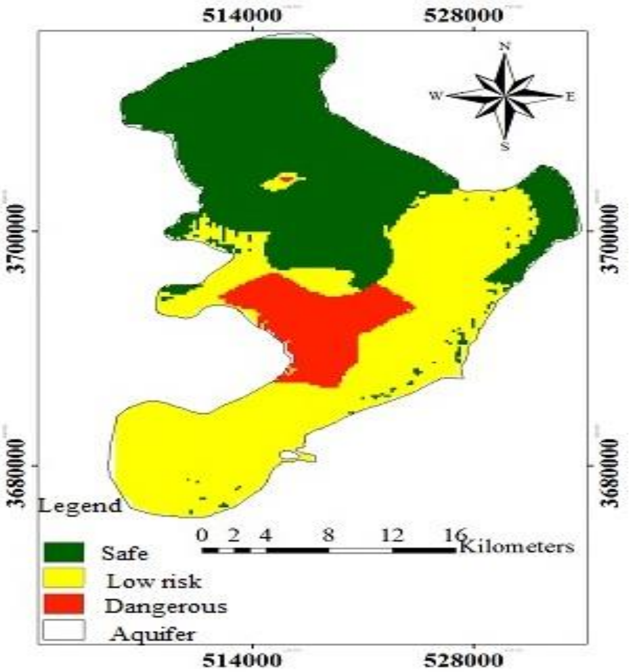

Fig. 6 Classification of aquifer quality privacy

groundwater resources of Meymeh aquifer is extracted (Fig. 6), Due to the concentration of nitrate, the final map of the quality of the Meymeh aquifer was categorized into three categories: safe, low risk and hazardous.

4.9 Verification of drastic model

Due to the fact that the data were not normal, Spearman method (non-parametric statistical method) was used to determine the correlation between nitrate concentration and local drastic index in sampling points. The results are presented in Table 4. As you can see in this table, there is no significant correlation between these two parameters (p value < 0.05).

Optimization of the drastic model is performed by weighting the factors based on statistical methods. Weighing reviews are obtained by examining the correlation of each parameter with the concentration of nitrate at the sampling points.

Based on the above table, for the Meymeh aquifer, two soil and topography parameters are omitted from the drastic model. After applying the corrected weights and removing the two non-dependent parameters, the new drastic index for the Meymeh aquifer is changed as follows:

Table 4 Spearman's coefficient between drastic index, new drastic index and nitrate concentration

			Nitrate Concentration	**New Drastic Index**
Spearman's rho	Nitrate Concentration	Correlation Coefficient	1	0.842
		Sig. (2-tailed)	0	0.002
		N	10	10
Spearman's rho		**Correlation Coefficient**	**Nitrate Concentration**	**Drastic Index**
		Sig. (2-tailed)	1	0.162–
		N	0	0.654
	Tests of Normality		10	10
Kolmogorov-Smirnova		Shapiro-Wilk		
Statistics	Sig.	Statistic	Df	Sig.
0.301	0.011	0.832	10	0.035
0.28	0.025	0.786	10	0.01

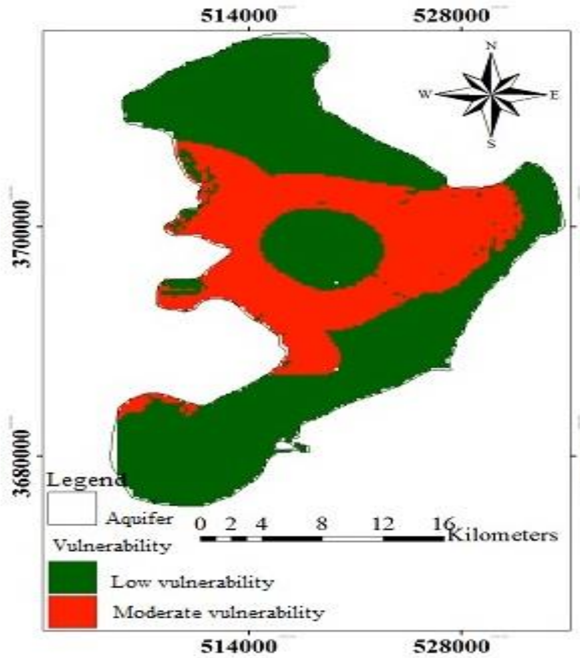

Fig 7. Meymeh aquifer zoning map by new drastic model

$$\text{DRASTIC index} = 5\,R + 3\,A + 5\,I + 5\,C \qquad (3)$$

After obtaining the new equation of the drastic model and calculating the new drastic index using Raster Calculation in ARCGIS environment, the correlation between nitrate concentration in groundwater samples and the new drastic index were again calculated. In this case, the correlation coefficient increased from - 0/162 (before optimization) to 0.842 (after optimization), The correlation was significant at 95% probability level. The vulnerability map of the Meymeh aquifer is presented using the new drastic equation in Fig.7. In this case, the range of vulnerability is reduced to between 41- 90. However, Meymeh aquifer is still classified in two categories: low and medium vulnerability.

5. Conclusion

According to the nitrate concentration zonation map, the highest concentrations in the groundwater of the southern part of the Meymeh aquifer were observed due to the interaction of pollution caused by agricultural activities, irrigation water reversal, land genus, higher feeding rates, hydraulic conductivity and soil permeability in this part of the aquifer. According to the drastic method, the vulnerability of the Meymeh aquifer is within the range of low and medium vulnerabilities (75- 128), A qualitative aquifer classification map was prepared by combining two vulnerability maps and zoning of nitrate concentration. According to this map, most of the study areas are in safe and low-risk areas, and only a small portion of the Meymeh Aquifer, where nitrate concentration in groundwater is higher than 50 mg / L, is classified in a hazardous area.

Based on the results, for the Meymeh aquifer, two soil and topography parameters are omitted from the drainage model. In this case, the vulnerability range is reduced to between 41- 90. However, the Meymeh Aquifer is still classified in two categories: low and medium vulnerability.

Considering the importance of contamination of water nitrate as one of the most important environmental and agricultural problems and also the value of groundwater resources, especially in arid and semi-arid regions and preventing their pollution to nitrate, it is recommended that the nitrate concentration of groundwater resources of the Meymeh aquifer at different depths, evaluated constantly and throughout the year.

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