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Modification of DRASTIC Model with Two Different Methods for Assessing Groundwater Vulnerability in Ardabil Plain

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Abstract

In the Ardabil Plain, groundwater is one of the most important sources of water supply. Therefore, quality protection and groundwater management are a research priority. Ardabil Plain is in danger due to agricultural activity's excessive consumption of fertilizers in the agricultural sector, livestock, and industrial centers effluent. Therefore, it is necessary to identify and monitor areas with high vulnerability potential. In this study, the vulnerability of the plain is first assessed using the DRASTIC method. The DRASTIC model is a general method and should calibrate in each area. So, this method was modified by two approaches. In the first approach, sensitivity analysis, and in the second approach, the amount of groundwater supply estimated by the WTF method was used. Then the vulnerability of Ardabil Plain was assessed. The results of the sensitivity analysis showed that the DRASTIC model in the Ardabil Plain area is susceptible to the parameters of Impact of vadose zone (I), Depth of groundwater (D), and aquifer media (A). The results also showed that the conventional model of the DRASTIC did not produce acceptable results compared to the Nitrate map. But calculating the amount of water recharge (R) by the WTF method, the correlation between the vulnerability maps and the Nitrate map was about 75%. In the second method, soil parameters (S) and hydraulic conductivity (C) did not have an acceptable correlation with the nitrate concentration in the groundwater of Ardabil Plain. These parameters were removed from the initial equation of the DRASTIC method, and the maps were prepared with the remaining parameters and with new weights and ratings, as a result of which the correlation between the new maps and the nitrate map reached about 30%. According to the WTF modified method for the DRASTIC model, the whole of the Ardabil Plain vulnerability maps in four areas was divided, including medium, high, very high, and infinitely highly vulnerable areas, and 25.8, 47.7, 15.1, and 11.4 percent, respectively.

Introduction

Groundwater is one of the most valuable water sources for drinking, agriculture, and industry needs worldwide, especially in arid and semi-arid regions (Li et al., 2017). In addition to the importance of groundwater quantity, its quality should be monitored and managed according to various threatening factors (Neshat et al., 2014). Groundwater quality has become a global challenge in recent years due to urban development and population growth (Wang et al., 2012). An essential point about groundwater quality is its gradual pollution and invisibility

(Vosoogh et al., 2017). In addition, treatment of groundwater pollution is a long, complex, and costly process (Huan et al., 2012). Therefore, maintaining and protecting groundwater quality against various contaminants is one of the crucial strategies for groundwater resource management (Mogaji & Lim, 2017). Anywhere, the potential for groundwater contamination depends on several physical and environmental factors, such as groundwater depth, soil type, and aquifer conditions (Fritch et al., 2000). Today, groundwater vulnerability assessment has become a valuable tool to prevent and protect aquifer water pollution (Huan et al., 2012). The vulnerability can be defined as the possibility of infiltration and spread of pollutants from the ground to the groundwater system (Besien, 2000). More than 30 methods for assessing aquifer vulnerability have been proposed by various researchers, divided into two general methods: (a) weight-based and indexing-based methods, (b) statistical and process-based methods. In the methods of the first group, managerial goals are decisive, while the methods of the second group are based on scientific aims. The use of the first group methods is more common (Wu et al., 2016). The DRASTIC method is one of the universally accepted methods used to assess the vulnerability potential of groundwater pollution in the plains (Li et al., 2017; Wu et al., 2016; Pacheco et al., 2006; Mimi et al., 2012; Kazakis & Voudouris 2015). This method is general, but since it does not provide satisfactory results in many cases, it should usually be modified to suit the conditions of each region. Researchers have proposed various solutions to modify the DRASTIC model. In general, some of these strategies are the Modification of initial defined weights and rankings (Sener & Davraz, 2013; Moustafa, 2019; Sadat-Noori & Ebrahimi, 2016; Wu et al., 2016; Wang et al., 2012; Abdullah et al., 2018). Another method that researchers use to modify the DRASTIC model is to correct the sensitivity analysis method (Wu et al., 2016; Wu et al., 2014; Mimi et al., 2012; Neshat et al., 2014; Chen et al., 2013). Other methods include addressing the weaknesses of the DRASTIC model by combining it with software such as Hydrous, GIS, or Analytic Hierarchy Process (AHP) (Xiaoyu et al., 2018; Mogaji & Lim, 2017; Li et al., 2017; Kazakis & Voudouris, 2015) .

In the DRASTIC method, estimating groundwater recharge (R) is one of the essential parameters that in most researches, a value for the whole plain is used. While due to changes in slope, soil type, lithology, land use, and other influential factors, the amount of groundwater recharge is a spatial variable (Xiaoyu et al., 2018; Massoud Lak et al., 2019; Panagopoulos et al., 2006; Abdullah et al., 2018). Naturally, the amounts of recharge in the plain are very different, therefore considering a number as a recharge indicator for a plain seems to decrease the vulnerability map accuracy (Ghafari et al., 2018). Also, in studies conducted by the DRASTIC method, the amount of recharge is considered only due to rainfall. However, return irrigation water is another recharge source of groundwater. In some plains, the share of return irrigation water could be greater than the portion of rainfall. Therefore, in this study, using the WTF (Water Table Fluctuation) method, the part of returned water and rainfall in groundwater recharge of Ardabil Plain has been estimated. Then, the recharge zonation due to return irrigation water and rainfall was drawn separately for the plain. Finally, in the DRASTIC method, the return irrigation water, and recharged rainfall were used instead of a unique recharge value throughout the plain.

Material and Methods

This study was performed on the aquifer of Ardabil Plain, NW Iran. The plain with an area of 1217 km^2, the aquifer is located in 48º 7 'to 48º 37 'east longitude and 38 º 2 ' to 38 º 31 ' north latitude (Figure 1). In this study, collected data in six meteorological stations (Ardabil, Ardabil airport, Namin, Abi Biglou, Hir, and Samian) with sufficient information were used. The average ten-year rainfall in this aquifer was 280 mm; the maximum monthly rainfall was 138.5 mm in May and belonged to Hir station. Also, the maximum annual rainfall of 501 mm is at the Hir station, and the minimum annual rainfall of 156 mm is related to the rainfall station of Ardabil airport .

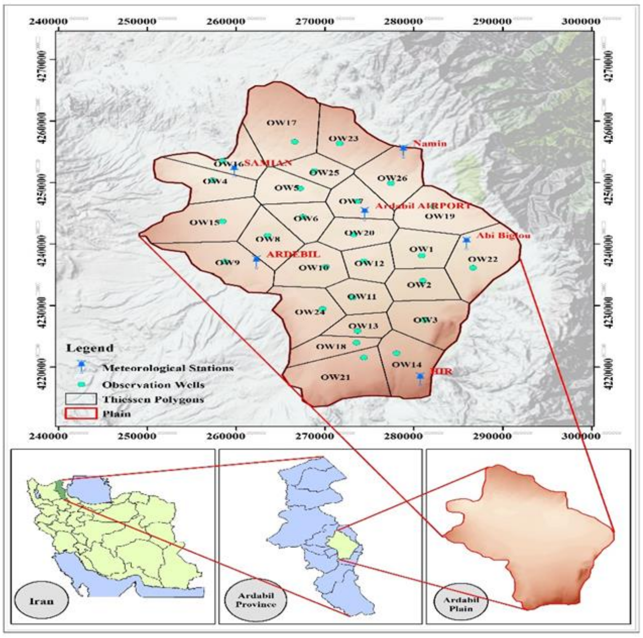

Fig 1- The study area (Ardabil Plain)

Table 1- Criteria rating of DRASTIC (Aller et al., 1987)

Rating	D (m)	R (mm/year)	A (media type)	S (soil type)	T (%)	I (media type)	C (m/day)
1	>30.5	0–51	Clay	Non-shrinking clay	>18	Clay	0–4.1
2	26.7–30.5	51–71.4	Loam	Backfill	17–18	Loam	4.1–12.2
3	22.9–26.7	71.4–91.8	Sandy loam	Clay loam	15–17	Sandy loam	12.2–20.3
4	15.2–22.9	91.8–117.2	Silt	Silty loam	13–15	Silt	20.3–28.5
5	12.1–15.2	117.2–147.6	Fine sand	Loam	11–13	Fine sand	28.5–34.6
6	9.1–12.1	147.6–178	Sand	Gravelly loam	9–11	Sand	34.6–40.7
7	6.8–9.1	178–216	Medium sand	Shrinking clay	7–9	Medium sand	40.7–61.1
8	4.6–6.8	216–235	Coarse sand	Peat	4–7	Coarse sand	61.1–71.5
9	1.5–4.6	235–254	Sand and gravel	Sand and gravel	2–4	Sand and gravel	71.5–81.5
10	0–1.5	>254	Gravel	Gravel	0–2	Gravel	>81.5

DRASTIC Model

The DRASTIC model is derived from seven parameters: groundwater depth (D), recharge (R), aquifer media type (A), soil type (S), topography (T), the effect of the unsaturated zone (I), and aquifer hydraulic conductivity (C) with weights of 5, 4, 3, 2, 1, 5 and 3, respectively. In this method, the vulnerability index is obtained from the sum of the product of weight multiplication and rank of the seven parameters mentioned above according to Eq. (1) (Beynen et al., 2012). The rank of each parameter varies between 1 and 10 according to its importance (Table 1) (Noori et al., 2019) .

$$\mathrm{DRASTIC} = \mathrm{R_d} \times \mathrm{W_d} + \mathrm{R_r} \times \mathrm{W_r} + \mathrm{R_a} \times \mathrm{W_a} + \mathrm{R_s} \times \mathrm{W_s} + \mathrm{R_t} \times \mathrm{W_t} + \mathrm{R_i} \times \mathrm{W_i} + \mathrm{R_c} \times \mathrm{W_c} \qquad (1)$$

where DRASTIC is the vulnerability index, W is the parameter weight, and R is the parameter rank. Indices d, r, a, s, t, i, and c respectively indicate groundwater depth, groundwater recharge, aquifer media type, soil type, and topography, the effect of the unsaturated zone, and hydraulic saturation of aquifer saturation. After calculating the vulnerability index, the zoning map of this index was prepared according to the qualitative classification of the vulnerability (Table 2).

Modifying the DRASTIC model by modifying the ranking and weight

The aquifer vulnerability index does not mean the existence of aquifer contamination but also requires the source of pollution to contaminate the aquifer (Massoud Lak et al., 2019). To verify the vulnerability map, a groundwater pollution index is required. For this purpose, in this study, the concentration of nitrate in groundwater was used. Therefore, correcting the ranks and weights leads to increasing the accuracy of groundwater potential vulnerability maps. For this purpose, the DRASTIC index was modified according to the method presented by Allouche et al., 2017 and Panagopoulos et al., 2006. In this method, to correct the DRASTIC model, each factor's amount of rank and weight is reviewed. The non-parametric Wilcoxon, 1945 statistical test was used to correct the rankings. This test statistically determines the difference between the mean of the two neighboring classes. The basis for reviewing the weights is based on the correlation between each parameter and the nitrate concentration for the points in the plain. The value of each factor varies according to a specific scale that uses the correlation coefficient defined by Spearman (Kendal, 1975). The non-correlation of each element with the nitrate concentration indicates that it has no effect on the nitrate concentration in the study area and is therefore removed from the primary DRASTIC model. Other factors that are significantly correlated with nitrate concentration are considered in the initial equation with the weight change. Each element with the highest correlation coefficient is assigned a weight of 5 (the highest weight defined according to the original model). Other weights are calculated by applying a coefficient of the ratio of the correlation coefficient of the factor to the maximum correlation coefficient is 5 (Allouche et al., 2017; Panagopoulos et al., 2006).

Sensitivity analysis of the modified DRASTIC model

The modified DRASTIC model uses a lot of data to calculate the vulnerability. Each data has an error which may cause uncertainty in the final results. To reduce this uncertainty, the model's sensitivity to each of the factors is usually measured. Sensitivity analysis is generally performed by parameter deletion and as a single parameter. In the parameter deletion method, the sensitivity of the DRASTIC model in estimating the vulnerability to delete a parameter is calculated through the following equation:

$$S_{xi} = \left(\frac{\left(\frac{V_i}{N} - \frac{V_{xi}}{n} \right)}{V_i} \right) \times 100 \qquad (2)$$

where, Sxi, Vxi, Vi, N, and n, respectively, sensitivity based on the deletion of parameter x, vulnerability index in case x parameter is deleted, vulnerability index in case no parameter is deleted, a total number of parameters and number are the remaining parameters. In the one-parameter sensitivity analysis, the effective weight of each parameter is compared with its parametric weight. The effective weight is a function of the value of one parameter relative to the other parameters, plus the weight assigned by the DRASTIC model. Each parameter with the effective weight factor (Wxi) is calculated as follows:

$$W_{xi} = \frac{X_{Ri} \times X_{wi}}{V_i} \times 100 \qquad (3)$$

where Wxi, XRi, Xwi, and Vi are the effective weight factor, rank and weight of the x parameter below the i-th region, and the vulnerability index calculated by the DRASTIC model, respectively.

Table 2- DRASTIC vulnerable index classification, Zhao et al., (2015)

DRASTIC Index	Range
Very Low	0- 55
Low	56-80
Moderate	81-113
High	114- 159
Very high	160-182
Extremely high	183- 230

Modification of DRASTIC model by calculating groundwater supply by WTF method

The WTF method provides an estimate of groundwater recharge using groundwater level fluctuations analysis. The only data required for this method is groundwater and specific discharge data. In this method, it is assumed that the increase in groundwater level in unconfined aquifers is due to water recharge the water table. The water recharge obtained from this method is estimated by Equation (4) (Ghafari et al., 2018):

$$\frac{\mathrm{dh}}{\mathrm{dt}} = \frac{\mathrm{R}}{\mathrm{S_y}} \quad \text{or} \quad \mathrm{R} = \mathrm{S_y}\frac{\mathrm{dh}}{\mathrm{dt}} \tag{4}$$

where R is groundwater recharge (LT-1), Sy is special discharge (dimensionless), dh is water level changes in the recharge period (L), and dt is the duration of the recharge period (T). In the extraction of Eq. (4), it is assumed that the water recharge the water table immediately becomes groundwater storage, and other components of the balance, including lateral flows during the recharge period, are zero (Pahlevani Majdabady et al, 2020). In this study, to comprehensively study the changes in groundwater level of Ardabil Aquifer by WTF method, 26 observation wells with sufficient information were selected within the aquifer boundary, and their Thiessen polygon was prepared in the ArcGIS software environment. Figure (1) shows the location of 26 observation wells and rain gauge stations used in this study along with the Thiessen polygon of observation wells and the location of aquifer operation wells and annual pumping rate. After extracting the observed changes in water level from the information of selected observation wells, precipitation values, values taken out of the aquifer through exploitation wells (1917 active wells), springs (23 permanent springs and 3 seasonal springs), and aqueducts (62 fields). The irrigation values in each area related to the observation well in the first 5 years and sorting them in Excel Software environment, then transferred to SPSS Software environment. Equation (4) can be rewritten as Eq. (5) by considering the mentioned components of water recharge. To calibrate the parameters, data analysis was performed based on Eq. (5).

$$\frac{dh}{dt} = \frac{\beta P}{S_y} + \frac{\lambda F_i}{S_y} - \frac{F_p}{S_y} \tag{5}$$

(5) Where is groundwater level fluctuations over time, Sy is specific discharge, P is the amount of monthly rainfall, I is the amount of monthly irrigation, Fp is the amount of pumping, and also changes in subsurface flows, which are: q = qin - qout (qin and qout are the input and output subsurface currents, respectively). If the subsurface flow leaving the polygon is more than the input, the negative sign in Eq. (5) is considered. Also, α and β coefficients fraction the amount of rainfall and return irrigation water, respectively, which recharge the aquifer. The total unit of parameters is monthly, except for the special discharge, which is dimensionless. Inverse Modeling (Forward) by considering it as a forward model (Eq. 5) and with the help of optimization algorithms to minimize the objective function (the difference between simulated values of groundwater level fluctuations by WTF method and observational values) with the software SPSS was performed. In the inverse method, by minimizing the objective function, the recharging parameters (precipitation fraction (α), irrigation fraction (β), and subsurface flows (q)) and Sy were estimated. In the inverse method, in the first 5 years, using the observed values of groundwater level fluctuations, the required parameters (α, β,

Sy, and q) in the calibration stage were estimated. Then, to measure the accuracy of the estimated parameters, in the second 5 years without using the inverse method, using the estimated parameters and Eq. (5), the simulations of the simulated groundwater level were compared with the observed values (validation step).

Because it is possible to create layers of different classification methods in the GIS environment, therefore, to evaluate the accuracy of classification methods, six classification methods (Equal Interval, Defined Interval, Quantile, Natural Breaks, Geometric Interval, etc. and Standard Deviation) was used to prepare a recharge map. To evaluate the effect of classification methods on the accuracy of groundwater vulnerability estimation, the Duncan test was used in the SPSS software environment and Taylor diagram.

Results and Discussion

Sensitivity analysis

The results showed that unsaturated media (I), water table depth (D), and aquifer media type (A) with an average of 13.74, 11.23, and 8.9%, respectively, had the highest sensitivity to the removal of layers in the Ardabil Plain (Table 3). Also, the DRASTIC model results showed the lowest sensitivity to the removal of the hydraulic conductivity layer (C) and the slope of the plain (T), with an average of 1.98 and 3.68% sensitivity to removal, respectively. The results of one-parameter sensitivity analysis showed that unsaturated media (I), water table depth (D), and aquifer media type (A) with an average of 27.19, 21.15, and 17.15% of the total weight, respectively (Table 4). Also, the lowest weight between different layers, hydraulic conductivity (C), surface slope (T), and soil type (S) with effective weights of 3.97, 7.62, and 8.53% of the total weight, in this method, the lowest showed sensitivity.

The critical point in this method is the number of changes in effective weights compared to theoretical weights. As shown in Table (4), theoretical weights also have different sensitivity ratings. Compared to theoretical weights, parameters (D) and (S) did not show a significant change. Also, regardless of the degree of sensitivity, parameters (I), (T), and (A) had a positive change (increase) and parameters (C) and (R) a negative change (decrease) to the percentage of theoretical weight.

Table 3- Statistics obtained from the removal of layers

Parameters	Index changes			St.dev
	Min	Average	Max	
DRASTI	1.78	1.98	2.11	0.09
DRASI	2.73	3.68	4.3	0.46
DRAI	2.3	6.12	8.02	1.35
DAI	3.74	8.09	11.97	2.46
DI	2.96	11.23	15.83	2.92
I	0.27	13.74	26.03	9.34

Table 4- Statistical results of one-parameter sensitivity analysis

parameters	Theoric Weight	Theoric Weight (%)	Effective weight (%)				Effective weight
			Min	Average	Max	St.dev	
D	5	21.74	7.75	21.5	42.7	10.89	4.86
R	4	17.39	8.22	14.39	28.07	5.25	3.31
A	3	13.04	2.63	17.15	24.19	7.06	3.95
S	2	8.7	3.23	8.53	20.41	4.46	1.96
T	1	4.35	5.43	7.62	11.49	1.74	1.75
I	5	21.74	10.95	27.19	40.32	9.68	6.25
C	3	13.04	2.72	3.97	6.02	0.94	0.91

Preparing a vulnerability map using the DRASTIC method

First, the DRASTIC method (Eq. 1) was used to prepare the vulnerability map of Ardabil Plain. After creating the required layers, a groundwater vulnerability map of the Ardabil Plain was prepared. Based on the classification made by Zhao et al., 2015, the vulnerability status was determined in the study area, and Ardabil Plain had a vulnerability in three classes: low (5%), medium (77%), and high (18%). Most of the plain (77%) is moderately vulnerable according to this method. About 18% of the plain is in a very vulnerable condition. Because the hydraulic conductivity and topography layers are the same for the whole plain, other layers are the cause of vulnerability changes in the Ardabil Plain. Taylor diagram was used to judge the accuracy of the prepared map (Fig. 2). This diagram simultaneously uses the criteria of correlation coefficient (Standard Correlation), standard deviation (Standard Deviation), and RMSE index. It allows the correlation value of two sets of information, the amount of error, information scatter, and correlation direction, to be determined. The results showed that the values of the initial DRASTIC model have the lowest correlation with the values of nitrate concentration (Base) (Fig. 2). Therefore, these results cannot be used to manage groundwater in the Ardabil Plain.

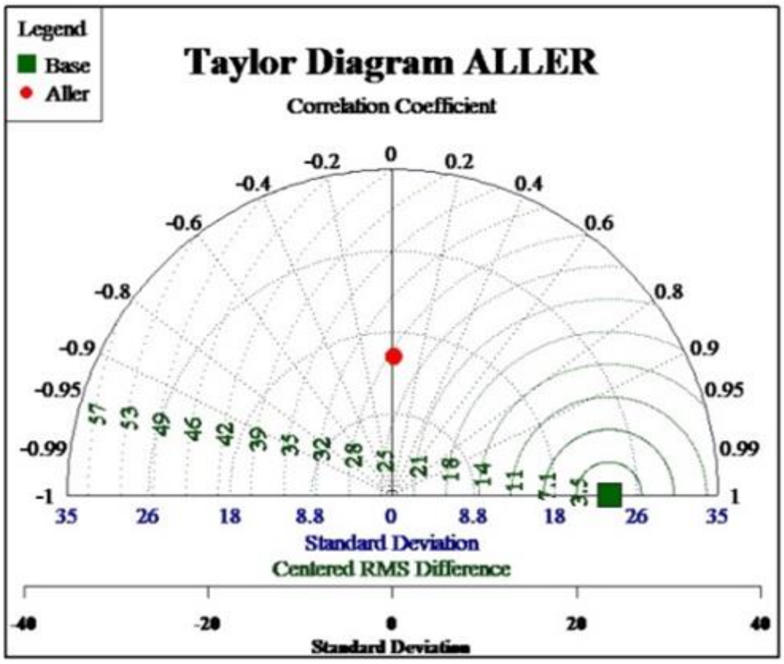

Fig. 2- Taylor diagram to compare the results of the DRASTIC model and the nitrate concentration

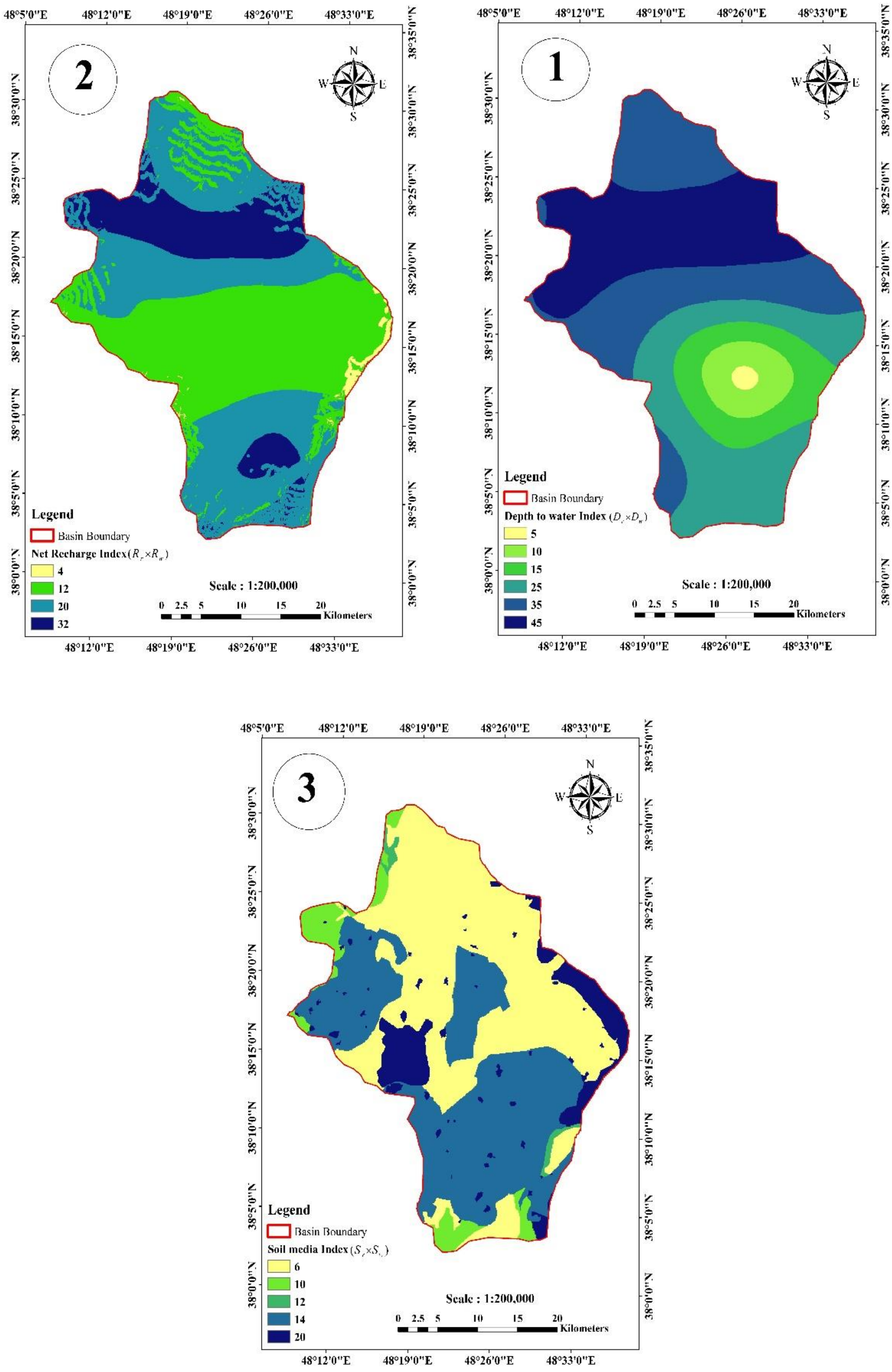

Fig. 3a- Three layers and DRASTIC model (1-Depth to groundwater 2-Net recharge 3-Aquifer media)

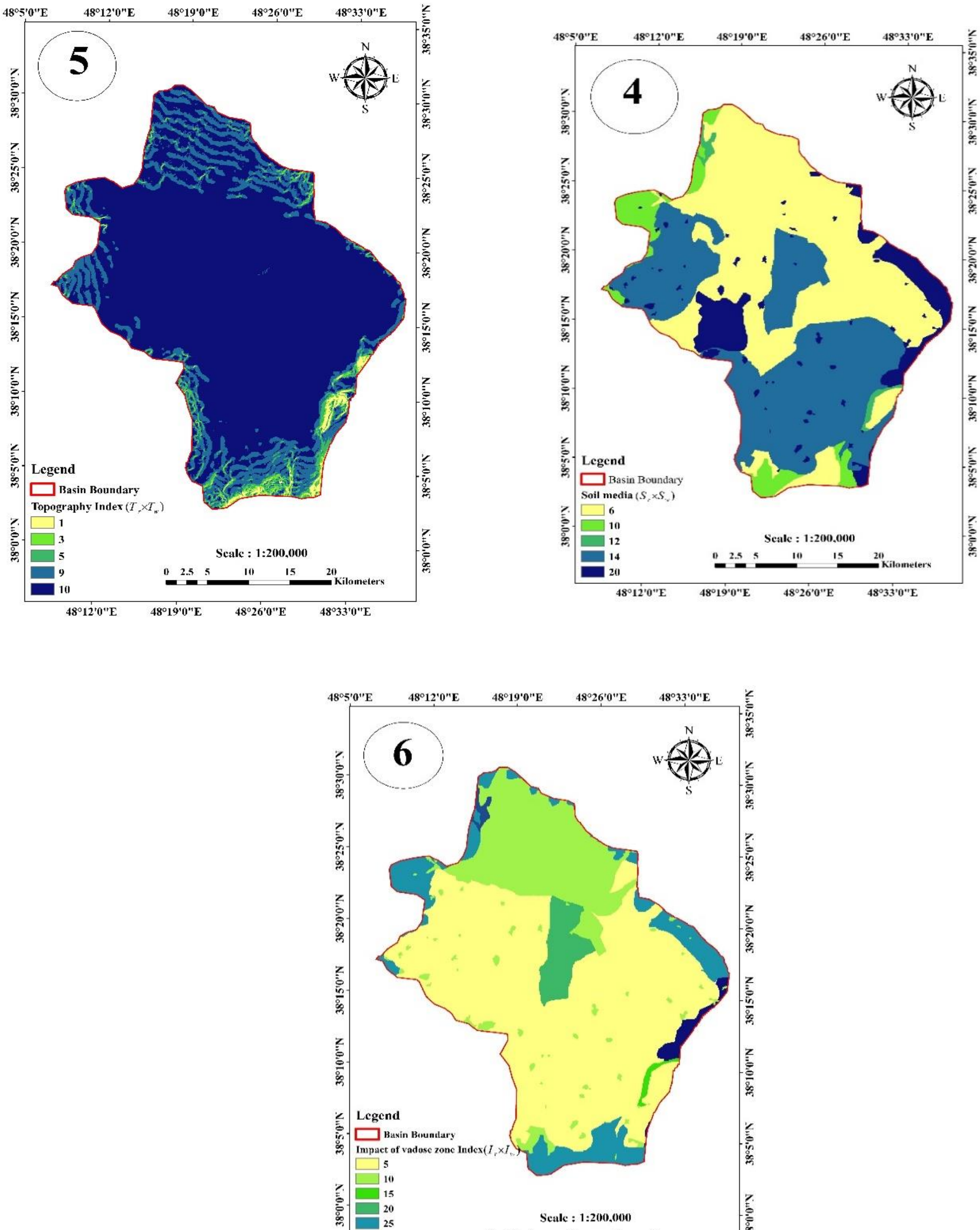

Fig. 3b- Three layers and DRASTIC model (4-soil media 5-topography 6-impact of the vadose zone)

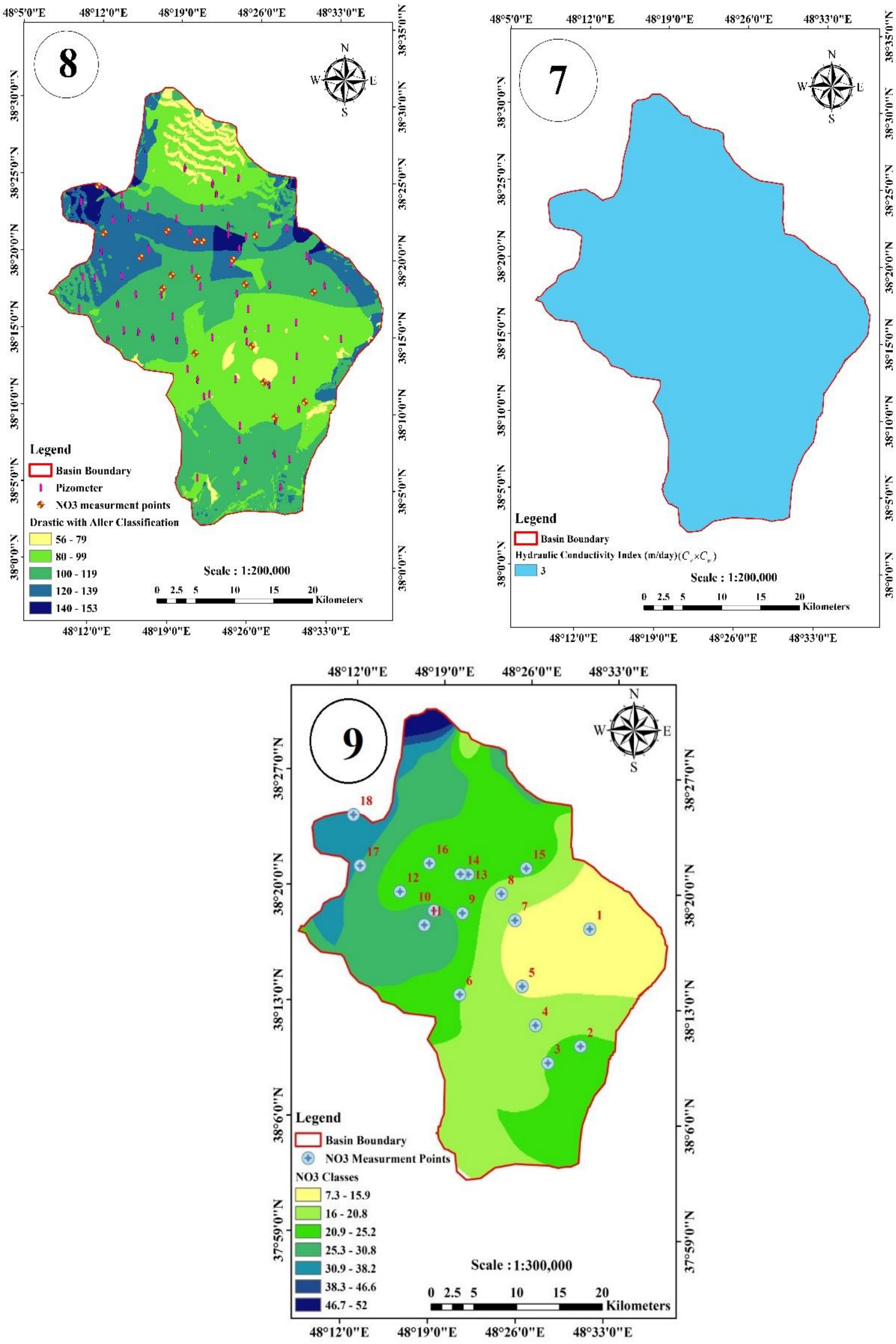

Fig. 3c- Three layers and DRASTIC model (7-Hydraulic Conductivity 8- DRASTIC model 9- NO3)

The layer map required to create the vulnerability map by the DRASTIC method showed that relatively high groundwater depth, unsaturated layer with low to medium impermeability in almost the entire Ardabil Plain, and groundwater recharge with small amount are the determining factors. As mentioned, in addition to the seven layers required to prepare a DRASTIC model of nitrate concentration zoning in Ardabil Plain, a vulnerability map was prepared (Figs. 3a to 3c).

Preparing the vulnerability map of DRASTIC method using WTF method

As described, the initial DRASTIC model showed a weak correlation between vulnerability zoning and nitrate levels for the study area. Also, the results of sensitivity analysis showed that the parameters of unsaturated environment (I), water table depth (D), and aquifer (A) are the most sensitive in the DRASTIC model. Still, these factors are an inherent feature of the plain, and only plain conditions and structural factors depend. Among the remaining parameters, the value of hydraulic conductivity (C) and net recharge (R), and the intrinsic characteristics of the aquifer also depend on the calculation method (Fig. 5).

On the other hand, according to Figs. (3a to 3c) and sensitivity analysis, the effect of hydraulic conductivity on the vulnerability map is the same in the whole plain, so one of the effective parameters in the Ardabil Plain on the groundwater vulnerability map is the value of recharge. To improve the results, the amount of groundwater recharge due to return irrigation water and recharge from rainfall was calculated by the WTF method. The amount of groundwater pollution vulnerability in Ardabil Plain was calculated by using the DRASTIC method. In addition to the effect of the recharge estimation method, six classification methods (Equal interval, Defined interval, Geometric Natural, Quantile, Standard deviation) were also examined. In this case, the study area was divided into 4 areas on average in terms of vulnerability. These areas include medium, high, very high, and high 3 T vulnerabilities and cover 25.8%, 47.7%, 15.1%, and 11.4% of the total plain, respectively (Fig. 4).

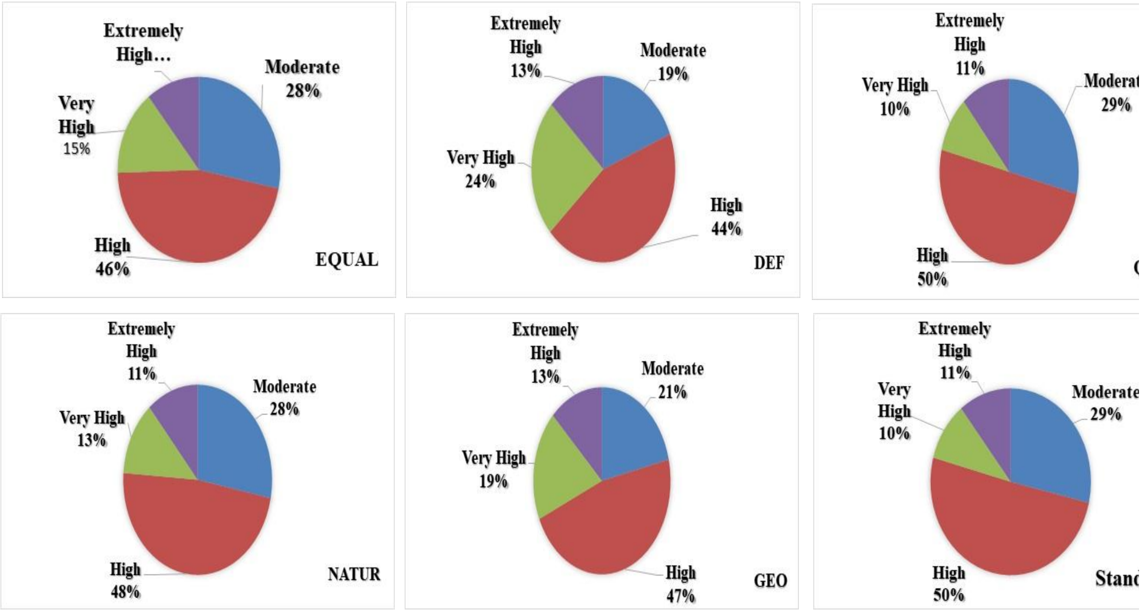

Fig. 4- Percentage of DRASTIC result Sixe DRASTIC model maps with net recharge estimated by WTF method

Considering the changes considered for better estimation of the vulnerability map, it is necessary to investigate the effectiveness of correcting the DRASTIC model and different classification methods in estimating the vulnerability of Ardabil Plain. Initially, different vulnerability values for different classifications were evaluated using a correlation matrix (Fig. 6). The results showed a high correlation (93% to 98%) between the different values related to each classification method. This high correlation may be due to the similarity of the results of different classification methods. Also, in the correlation matrix, the amount of nitrate concentration was used as a base criterion to evaluate the accuracy of the results. The value of this correlation is given in the first row of Fig. (7). Compared to the original DRASTIC method, the correlation value has increased. If a negative sign is indicated in the correlation values, the models have produced the opposite answer than the primary criterion. In other words, in any place where the vulnerability index has a larger number, the nitrate concentration is lower and vice versa, which cannot be true given the physics of the problem and the initial assumptions. But as it is clear from the numbers in the first row (opposite the Base phrase), there are positive signs and a relatively acceptable correlation (76-79%). This correlation can be seen visually by comparing Fig. (6) images and changes in nitrate concentration in Ardabil Plain.

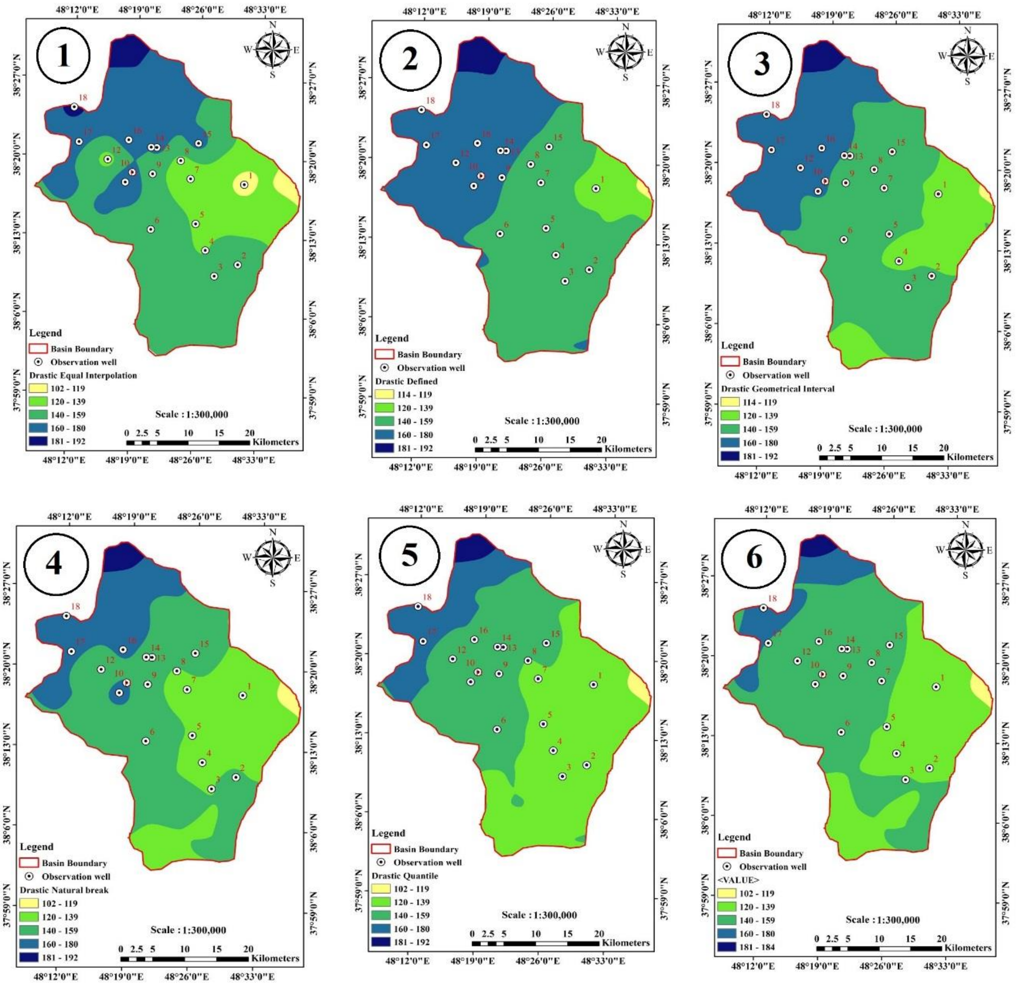

Fig. 5-Sixe DRASTIC model maps with net recharge estimated by WTF method (1-equal interval 2-defined interval 3-geometrical 4-natural 5-quantaile 6-standard dev.)

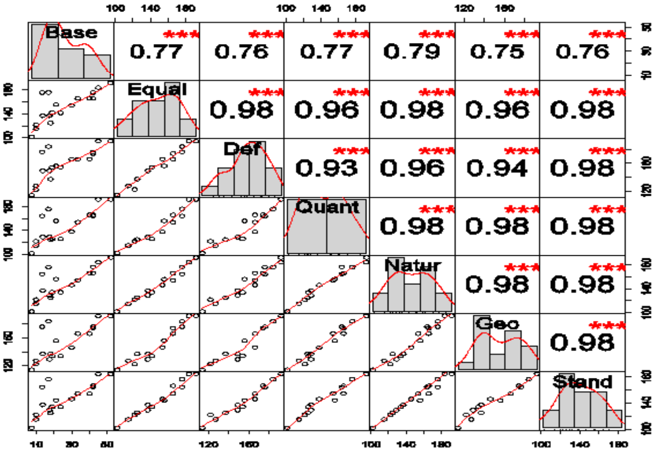

Fig. 6-Matrix correlation of vulnerability values with different classification methods in WTF method

Table 3- Comparison of the average results of vulnerability with different classification methods (WTF)

Source of changes	sum of squares	df	Mean of squares	F	Sig
Between groups	1950.963	5	390.193	0.626	0.68
Within groups	63588.889	102	623.42		
Total	65539.852	107			

In the next step, to ensure the effectiveness of the classification method on the results of estimating the groundwater vulnerability of Ardabil Plain, the means were compared in SPSS software (Table 3). It should be noted that the comparison of means was made by the Duncan method with alpha = 0.01. The results showed that the different values were not statistically significant. In other words, various classification methods did not affect the results related to the calculation of groundwater vulnerability in Ardabil Plain. Therefore, it can be said that using any of the information classification methods in a GIS environment does not make a significant difference in the final results.

The more the changes in groundwater vulnerability index in each plain are in line with changes in nitrate concentration, the higher the correlation value, standard error, and lower RMSE indicate the desirability of that method. The Taylor diagram was used to evaluate the alignment of changes in groundwater vulnerability index with changes in nitrate concentration (Fig. 7). A series of different results in the WTF method on the Taylor diagram can be seen in region 1 (positive correlation).

Valuation of vulnerability potential in modified DRASTIC model and comparison with nitrate zoning map

The results of sensitivity analysis of the single parameter removal method and determining the degree of sensitivity of the parameters showed that the initial weights need to be modified to achieve greater accuracy (Table 4). The results showed that the parameters of soil type (S) and hydraulic conductivity (C) did not have the necessary correlation with the concentration of nitrate in groundwater in Ardabil Plain, so it was removed from the equation for a new evaluation (Table 5). Accordingly, the new weights for the existing numbers for the first, second, third, fifth, and sixth factors were 2.45, 3.17, 4.1, 2.9, and 5, respectively (Table 5). Also, the negative Spearman coefficient for factors D and T Table (5) is consistent with the physics of the problem. It means that the shorter the distance to groundwater, the greater the likelihood of groundwater contamination if there is a source of contamination. Also, the lower the basin slope, the greater the opportunity for penetration and transfer from the surface. According to the corrections made for weights, Eq. (1) was modified as Eq. (6):

$$(DRASTIC)_i = 2.45 \times D + 3.17 \times R + 4.1 \times A + 2.9 \times T + 5 \times I \qquad (6)$$

Soil (S) and hydraulic conductivity (C) parameters were removed from the model constituent layers, and the plain vulnerability index was obtained by combining groundwater depth layers, net nutrition, aquifer, topography, and unsaturated environment (using the results in Table 6).

The results obtained by comparing the zoning map and the distribution of nitrate concentration in the plain show the beater correlation. The correlation coefficient between the two factors was about 30%, shown in Fig. (8). In this model, the north and northwest of the plain, which had a high nitrate concentration, had a high potential for vulnerability. The correlation coefficient of this model increased to about 30% in the original state of the DRASTIC model.

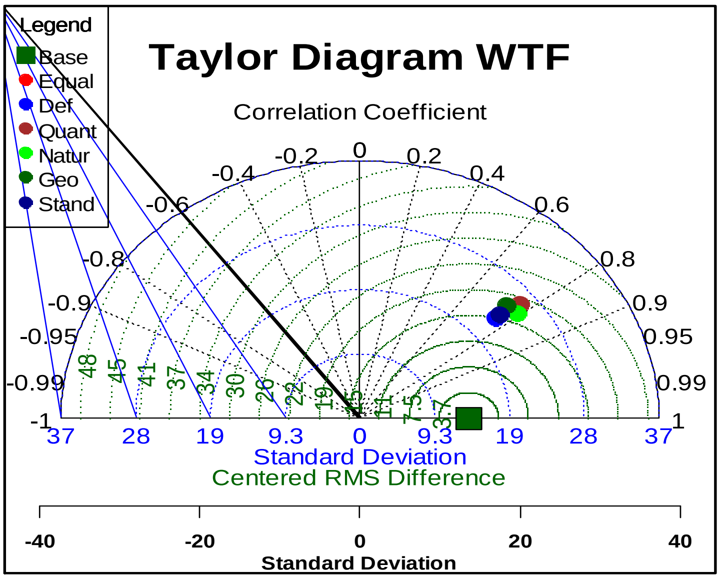

Fig. 7 - Taylor diagram for comparing the results of the DRASTIC model (WTF) and the nitrate concentration

Table 5- Original and modified weights of the DRASTIC factors and correlation coefficient between DRASTIC factors and nitrate concentration

DRASTIC factors	Original weight	Spearman's rho coefficient	p-value	Modified weight
Depth to groundwater (D)	5	-0.382	0.0122	2.45
Recharge (R)	4	0.495	0.102	3.17
Aquifer type (A)	3	0.633	0.000	4.1
Soil type (S)	2	0.133	0.524	-
Topography (T)	1	-0.449	0.0104	2.9
Impact of vadose zone (I)	5	0.780	0.00	5
Hydraulic conductivity (C)	3	0.0752	0.925	-

Table 6-Modified ranking of different layers in DRASTIC model

Depth to Groundwater				Recharge (R)			Aquifer type (A)		
Rating	D (m)	No3 (mg/lit)	New Rating	R (mm/year)	No3 (mg/lit)	New Rating	A	No3 (mg/lit)	New Rating
1	>30.5	-	-	0–51	-	-	Clay	-	-
2	26.7–30.5	17.4	3.3	51–71.4	-	-	Loam	-	-
3	22.9–26.7	-	-	71.4–91.8	18.8	3.24	Sandy loam	13.55	2.6
4	15.2–22.9	22.1	4.1	91.8–117.2	23	3.98	Silt	-	-
5	12.1–15.2	-	-	117.2–147.6	18	4.85	Fine sand	23.75	4.6
6	9.1–12.1	33.4	6.4	147.6–178	45	7.74	Sand	-	-
7	6.8–9.1	-	-	178–216	-	-	Medium sand	-	-
8	4.6–6.8	45	8.6	216–235	49	8.48	Coarse sand	-	-
9	1.5–4.6	52	10	235–254	52	9	Sand and gravel	-	-
10	0–1.5	–	–	>254	-	-	Gravel	33.4	6.4

Continuation of Table 6

Topography				Impact of vadose zone		
Rating	T (%)	NO3(mg/lit)	New Rating	I	NO3(mg/lit)	New Rating
1	>18	-	-	Clay	7.8	1.5
2	17–18	-	-	Loam	14.3	2.8
3	15–17	-	-	Sandy loam	9.5	1.8
4	13–15	-	-	Silt	16.8	3.2
5	11–13	-	-	Fine sand	22	4.2
6	9–11	-	-	Sand	35	6.7
7	7–9	-	-	Medium sand	27	5.2
8	4–7	-	-	Coarse sand	29	5.6
9	2–4	-	-	Sand and gravel	-	-
10	0–2	52	10	Gravel	-	-

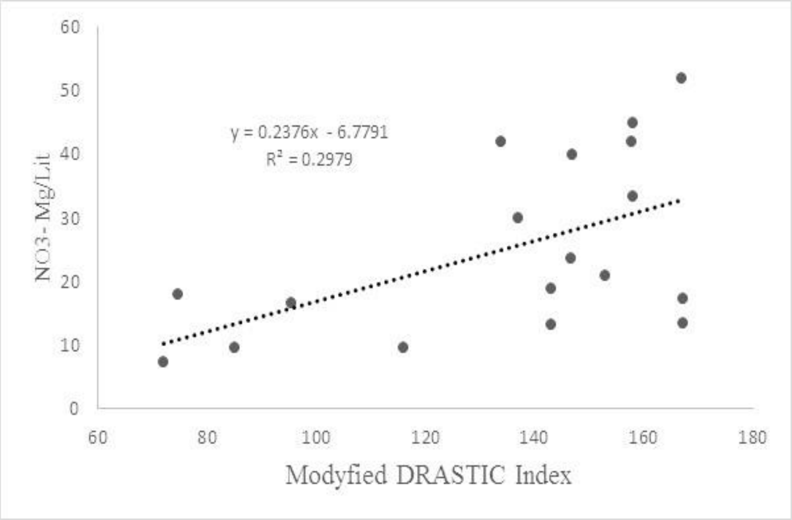

Fig. 8 - Comparison of the damage map of the modified DRASTIC model with the nitrate values

Conclusion

This study hypothesized that different methods of results classifying the results could affect the value of the vulnerability index in different parts of the plain. For this purpose, vulnerability values were calculated by different classification methods. Then the means were compared using Duncan's test method. The results showed that using any of the classification methods in the study area and available information did not significantly affect the vulnerability zoning map. The results also showed that the initial DRASTIC model, in comparison with the nitrate concentration index, does not evaluate the groundwater vulnerability of Ardabil Plain to pollution as acceptable. Two different approaches were used to modify the original DRASTIC model. First, the values of the vulnerability index of the model were prepared using the WTF method to estimate the groundwater supply. The vulnerability index obtained from the WTF method compared to nitrate concentration (correlation more than 75%) showed that this method has improved the results. Based on the results of this method, Ardabil Plain was divided into four areas in terms of vulnerability. These areas include moderate, high, very high, and extremely high vulnerabilities and cover 25.8, 47.7, 15.1, and 11.4 percent of the total plain. The second approach to modify the DRASTIC model was to modify the weights and ranks according to which the parameters of soil type (S) and hydraulic conductivity (C) did not have the necessary correlation with nitrate concentration in groundwater of Ardabil Plain and from the initial equation deleted, and the weight of other parameters including; Depth of water table (D), groundwater recharge (R), aquifer media type (A), surface slope (T) and unsaturated environment (I), respectively 2.45, 3.17, 4.1, / 9 2 and 5 were determined, after which the correlation coefficient of the DRASTIC index reached about 0.3, but did not reach an acceptable number. The results of sensitivity analysis of different parameters and the method of correcting weights and ranks almost together show the sensitivity of the DRASTIC model in the Ardabil plain to the parameters of unsaturated environment (I), water table depth (D), and aquifer media type (A). Also, hydraulic conductivity (C) and soil type (S) had the least weight and impact on the vulnerability map of the Ardabil Plain aquifer.

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