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GROUNDWATER VULNERABILITY ASSESSMENT USING A GIS BASED MODIFIED DRASTIC MODEL IN THE SHAHREKORD AGRICULTURAL AREA, IRAN

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Abstract: Intense agriculture activities and fertilizer application result in groundwater contamination, which has become a critical issue in recent years. Sustainable development, especially in arid and semi-arid regions relies on the availability of good quality water resources. One of the important components in groundwater management plan is vulnerability assessment of aquifers to contamination. Groundwater susceptibility to pollution can be determined using DRASTIC model. This model is the most widely used method for vulnerability mapping which consists of seven hydrogeological factors. Despite its popularity, this technique disregards the type of pollution and the effect of regional characteristics. Also, there is not a specific validation method to demonstrate the accuracy of this method. Thus, this model could be modified according to specifications of pollutants and aquifers. The more accurate and reliable vulnerability assessment can be implementing by adjusting rates of DRASTIC parameters using Wilcoxon rank-sum non parametric statistical test. The main goal of this research was to develop an integrated GIS-based DRASTIC model using statistical methods for adjusting rates of DRATSIC model. The relationship between each parameter and nitrate concentration in groundwater was identified using Wilcoxon rank-sum non parametric statistical test. This methodology was implemented for the Shahrekord aquifer, as a case study, located in southwest of Iran. Nitrate concentrations in 17 monitoring wells were used to correlate DRASTIC index to contamination in the aquifer. As a consequence, the new rates were calculated to estimate vulnerability index in different regions. Pearson's correlation results indicated that the modified DRASTIC is more efficient than standard DRASTIC and it showed a higher correlation coefficient with more contaminated areas represented by measured nitrate levels in wells.

1 INTRODUCTION

Groundwater could be considered as one of the most important natural resources in order to develop a society, especially in arid and semi-arid regions. Despite the significance of groundwater as the most important component of sustainable development, it has not received enough attention when it comes to its protection. In recent years, this economic resource has been at risk of depletion and pollution (Konikow et al. 2005) therefore, it seems vital to protect it from chemical pollution and deterioration. If an aquifer gets polluted, then remediation would be difficult and even impossible (Kavanaugh 1996). During last decades, extensive agricultural activities, municipal and industrial wastes have caused an increase in contaminants release into subsurface environment. Nitrate, one of the predominant contaminants associated with agricultural activities, has high solubility and mobility that could be a serious threat to contaminate groundwater resources. Hence, environmental managers and relevant authorities have been interested in evaluation of groundwater vulnerability to pollution and likelihood of contaminants concentration exceeding acceptable levels (Pardo-Iguzquiza et al. 2015). The concept of groundwater

vulnerability to contamination was developed by Margat which provides a better understanding of groundwater sensitivity against pollution with respect to geological, hydrological and meteorological conditions (Margat 1968). Groundwater vulnerability is a relative, dimensionless and non-measurable feature which relies on geological and hydrogeological properties of an aquifer (Antonakos et al. 2007).
DRASTIC is one of the most well-known and widely used parametric vulnerability mapping techniques. It was developed through an EPA (Environmental Protection Agency) project in United States with the purpose of helping managers, planners and administrators. It can be used in extensive regions due to low cost of application and easy to apply in Geographic Information Systems (GIS). DRASTIC has been applied in many regions to evaluate groundwater vulnerability, for instance in Iran (Mohammadi et al. 2009), Jordan (Al-Adamat et al. 2003), Europe (Carreras et al. 2015), United states (Plymale et al. 2002) and Africa (Ouedraogo et al. 2016). DRASTIC acronym stands for quantitative and categorical variables including: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity. The system is according to Delphi approach accomplished by a committee of experts so they may not be changed (Aller et al. 1987). Despite of simplicity and popularity, there are some weaknesses in vulnerability mapping using the DRASTIC technique. The main drawback is its subjectivity and doubts regarding the selection of specific parameters and exclusion of others (Panagopoulos et al. 2006). It disregards the effect of regional characteristics by assigning uniform rates and weights to parameters. Also, this technique does not use a standard validation method. Therefore, many researchers have attempted to modify DRASTIC model in order to achieve a more accurate vulnerability assessment (Pacheco et al. 2015, Ouedraogo et al. 2016). Neshat (2014) modified the rates and weights of standard DRASTIC using nitrate concentrations and single parameter sensitivity analysis, respectively. This methodology was implemented in the Kerman plain in the southeast region of Iran and revealed that the modified DRASTIC model performs more efficiently than the original method, particularly in agricultural areas (Neshat et al. 2014). Also, Abdullah (2016) modified the DRASTIC using Wilcoxon rank sum non-parametric statistical technique for groundwater vulnerability in Iraq and demonstrated that modified DRASTIC was dramatically superior to the standard model (Abdullah et al. 2016). In addition, Noori (2016) applied rate modification on Saveh-Nobaran plain in central Iran using chloride concentrations in groundwater and showed that the coefficient of determination between the point data and the relevant vulnerability map increased significantly from 0.52 to 0.78 after modification (Noori et al. 2016).

The contribution of this research was the modification of DRASTIC using nitrate concentrations which were measured in agricultural wells in the study area. The study area is the Shahrekord plain located in the southwest part of Iran. The majority of the study area is covered with agricultural lands, and the application of fertilizers is a common practice. The DRASTIC model can be applied to demonstrate the application of the proposed method and to provide a basis for its environmental management.

2 STUDY AREA

This research was conducted in Shahrekord aquifer, located at southwest Iran, between 32°7′N and 32°35′N latitudes and 50°38′E and 51°10′E longitudes. The Shahrekord plain has an area of 270 square kilometers. Majority of the study area is agricultural land and the rest is urban area, river and trees. Based on the topographic maps of the region, the highest ground elevation in the area is 2502 m, with the lowest point being 2014 m above sea level. For monitoring purposes, water levels were measured monthly in 25 observation wells.

3 MATERIALS AND METHODS

3.1 Data and DRASTIC model

The parameters in the DRASTIC method are included: Depth to water, Net recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and Hydraulic conductivity. The vulnerability index in DRASTIC was calculated by Eq. 1:

[1] $V = \sum_{i=1}^{7} W_i \times R_i$

Where V is the DRASTIC index, and W_i is the weighted coefficient for parameter i, with an associated rating value of R_i. Each of hydrogeological factors is given a rating from 1 to 10, and the DRASTIC parameters were assigned a weight from 1 to 5 according to their relative contribution to the potential pollution. The calculated index provides a relative measure of potential vulnerability of the aquifer to pollution and regions with a higher vulnerability index are more vulnerable. The rates and weights of the original DRASTIC model parameters were presented by Aller et al.(1987). In the current study, the data related to the hydrogeological parameters of the DRASTIC model were provided by Provincial Soil and Water Authorities of Shahrekord as listed in Table 1. All required layers for DRASTIC vulnerability evaluation were created using ArcGIS; each layer was classified using the different rating scales based on standard DRASTIC rating system.

Table 1: Sources of data used for creation of parameter in DRASTIC method

Type of Data	**Sources**
Hydrological	Meteorological Organization of Shahrekord
Soil map	Soil and water research Institute of Shahrekord
Topography	Water organizations of Shahrekord
Wells	Water organizations of Shahrekord
Hydraulic conductivity	Water organizations of Shahrekord
Groundwater balance of Shahrekord plain	Water organizations of Shahrekord

3.1.1 Depth to Water

The depth to water table was measured at 25 observation wells in Shahrekord plain. The Geostatistical Analyst extension in ArcGIS was applied to interpolate the points and create a raster map with a pixel size of 50 m using spline interpolation method. The depths to the water levels for the Shahrekord plain were classified according to original DRASTIC system, into five classes: 4.6 to 9 m, 9 to 15 m, 15 to 22 m, 22 to 30 m and more than 30 m, with depth to water rates of 7, 5, 3, 2 and 1, respectively.

3.1.2 Net Recharge

In general, rainfall infiltration, irrigation return flow, and absorption wells are defined as the net recharge. Recharge would provide transportation for pollution to reach water table, thus, the aquifers with more net recharge have higher vulnerability to contamination. Total net recharge in Shahrekord aquifer, was computed from the rainfall data by the Provincial Water Authorities in Shahrekord. Net recharge map was also created using ArcGIS. Net recharge for the Shahrekord plain was classified into four classes: 80 to 100 mm/year, 100 to 180, 180 to 250 mm/year, and more than 250 mm/year, with net recharge rates of 3, 6, 8, and 9, respectively.

3.1.3 Aquifer Media

Classification of aquifer media was performed using a subsurface geology map, geological sections, and drilling logs of the Shahrekord aquifer. Aquifer media for the Shahrekord plain was classified into one class which was sand and gravel, with aquifer media rate of 8.

3.1.4 Soil Media

The soil type is important in terms of the amount of net recharge which can reach the groundwater system. The soil map by Soil and Water Institute of Shahrekord was rated according to the original DRASTIC system. Based on this classification, coarse soil media have high rates in comparison to fine soil media. Soil media for the Shahrekord plain was classified into three classes which were clay loam, sandy loam and peat with soil media rate of 3, 6 and 8, respectively.

3.1.5 Topography

Topography indicates the slope of land which controls the probability that a pollutant run off or remain on surface to infiltrate. The slope was divided into five classes. The dominant slope range of the area is between 0 to 2 percent which mostly covers agricultural areas. The slope classes are 0 to 2 percent, 2 to 6, 6 to 12, 12 to 18 and higher than 18 percent with slope rate of 10, 9, 5, 3 and 1, respectively.

3.1.6 Impact of Vadose Zone

The impact of the vadose zone was classified based on the drilling logs in Shahrekord plain by the Provincial Water Authorities. The bedrock types within the study area were bedded limestone and sandstone. The impact of vadose zone was classified into one class, representing the bedded limestone and sandstone with impact of vadose zone rate of 6.

3.1.7 Hydraulic Conductivity

The water infiltration ability of aquifer media can be represented by hydraulic conductivity. Therefore, higher level of conductivity implies higher level of contamination. In Shahrekord plain, hydraulic conductivity distribution map was generated using pumping test results and a geophysical geoelectric study of the area by the Provincial Water Authorities. Areas with maximum hydraulic conductivity can have higher likelihood of pollution. Hydraulic conductivity for Shahrekord plain was classified according to original DRASTIC system, into three classes: 2.5 to 5, 4 to 12 and 12 to 14 m/day, with hydraulic conductivity rates of 1, 2 and 4, respectively.

3.2 Nitrate Measurement

Since the majority of Shahrekord plain is covered by agricultural land with extensive fertilizer application, nitrate concentration was selected as the main parameter indicating the groundwater pollution in the region. Some agricultural wells were selected for the analysis and sampling, with two nitrate samples collected from each well during two different months. The first set nitrate samples, a total of seventeen samples, were obtained in May 2007 and the second set of nitrate samples were collected in July 2007. One set was used for modification of DRASTIC model (fifteen samples) and the other set (seventeen samples) was used for validation purposes and to determine the correlation coefficient between the nitrate concentration and groundwater vulnerability.

3.3 Methodology

DRASTIC disregards the effect of regional characteristics, so the rates and weights are uniform. Many researchers have attempted to modify this model to achieve a more reliable vulnerability assessment. There are numerous methods to adjust standard DRASTIC technique. For Shahrekord vulnerability assessment, the rates of original DRASTIC have been modified using Wilcoxon rank sum non-parametric statistical test. This method can modify the rates in DRASTIC method by using the observed nitrate concentrations as a main factor. In fact, the relationship between the vulnerability index and the parameters can be statistically analyzed to adjust the rates. In order to optimize the rates of DRASTIC method using nitrate concentrations, the following requirements must be met (Panagopoulos et al. 2006):

- Nitrate must be a result of agricultural activities in the region.
- The distribution of nitrate should be relatively uniform in the area.
- Nitrate reached the groundwater by precipitation

In the study area, agriculture is the primary activity, thereby ensuring that these basic conditions are satisfied. All required layers for DRASTIC vulnerability evaluation were created using ArcGIS; each layer was classified using the different rating scales based on standard DRASTIC rating system. Then, DRASTIC index which is dimensionless index was determined by multiplying the rated rasters by the weight factor. Lack of a standard validation method is one of the common reasons to criticize DRASTIC approach. In Shahrekord plain, agriculture is primary activity and since nitrate does not exist in groundwater naturally, therefore nitrate can be considered as a good indicator of pollution. In the current research, correlation between DRASTIC index and nitrate concentrations were used to show whether the vulnerability map appropriately represents the actual situation in the study area. In fact, the vulnerability index would increase with the increasing nitrate concentration in the region. Therefore, Pearson’s correlation coefficient was calculated to validate vulnerability map.

4 RESULTS AND DISCUSSION

The intrinsic vulnerability map was divided to four classes as presented in Figure 1. In order to validate the vulnerability map, the correlation between vulnerability index and nitrate concentrations obtained from 15 wells in May 2007, was calculated. Table 2 display the results of correlation calculation. This value is indicating that the standard vulnerability index must be modified to obtain a realistic assessment of the potential contamination in the Shahrekord plain. In order to modify rates of standard DRASTIC using observed nitrate concentrations, the average of nitrate concentrations were calculated in each class for each layer. Then the highest mean of nitrate concentration was correlated with the highest rate and other rates were modified linearly based on this relation. Using 17 sampled points in July 2007, the rates of original DRASTIC have been modified. Aquifer media and impact of vadose zone had only one class in all the regions therefore, only the rates of the depth to water, net recharge, soil media, topography and hydraulic conductivity were modified based on the mean nitrate concentration as shown in Table 3.

In order to compare the rates used to calculate the original and modified DRASTIC index, the statistical summary of them were provided in Table 4 and 5. In the original DRASTIC, the highest risk of contamination (8 and 9) of groundwater in Shahrekord aquifer were due to aquifer media and the topography parameters. The soil media, net recharge and impact of vadose zone showed moderate risks of contamination (5 and 6) while depth to water and hydraulic conductivity impose a low risk of aquifer contamination (3 and 1). Depth to water, net recharge and hydraulic conductivity are moderately variable (CV% are 43, 41 and 39, respectively) while soil media and topography are less variable (CV% are 24 and 14, respectively). In rate modified DRASTIC, the highest risk of contamination (8 and 9) of groundwater originates from net recharge, aquifer media, soil media and the topography parameters. While depth to water, hydraulic conductivity and impact of vadose zone, implied moderate risks of contamination (5 and 6). Depth to water and hydraulic conductivity were moderately variable (CV% are 30 and 26, respectively) while soil media, net recharge and topography were less variable (CV% are 9, 13 and 17, respectively). Also in both original and modified DRASTIC, the rate of aquifer media and impact of vadose zone were constant in the whole area.

Table 2: Correlation factors between nitrate concentrations and standard DRASTIC index

Pearson’s correlation coefficient	Number of data	Factor
1	15	Nitrate Concentration
-0.3	15	DRASTIC Index

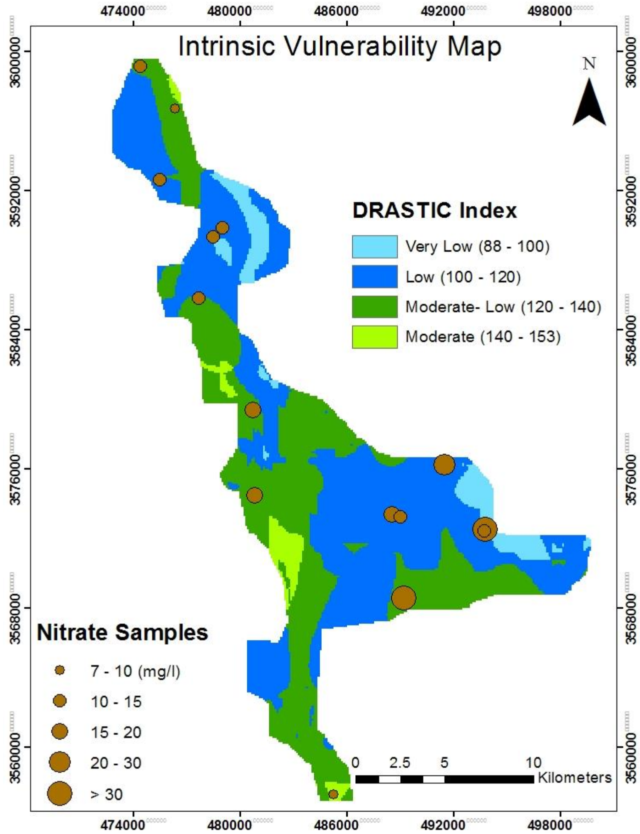

Figure 1: Intrinsic vulnerability map for the study area

Table 3: Standard and modified DRASTIC rates based on nitrate concentrations in the study area

Parameter	Range	Standard rate	Mean NO_3 (mg/l)	Modified rate
Depth to Water (m)	4.5-9	7	17.75	5.56
	9-15	5	10.65	3.33
	15-22	3	21.02	6.58
	22-30	2	16.38	4.81
	>30	1	31.95	10
Net Recharge (mm/year)	80-100	3	21.3	10
	100-180	6	17.75	8.33
	180-250	8	17.75	8.33
	>250	9	14.2	6.67
Soil Media	Clay Loam	3	22.48	10
	Sandy Loam	6	18.26	8.12
	Peat	8	No data	8
Topography (Slope %)	0-2	10	19.64	10
	2-6	9	16.23	7.24
	6-12	5	No data	5
	12-18	3	No data	3
	>18	1	No data	1
Conductivity (m/d)	2.5-4	1	14.2	4
	4-12	2	20.24	5.7
	12-14	4	35.5	10

Table 4: Statistical summary of rates in original DRASTIC

	D	R	A	S	T	I	C
Minimum	1	3	8	3	1	6	1
Maximum	7	9	8	8	10	6	4
Mean	3.33	5.43	8	5.32	9.51	6	1.87
SD	1.44	2.25	-	1.32	1.36	-	0.73
CV (%)	43	41	-	24	14	-	39

Table 5: Statistical summary of rates in modified DRASTIC

	D	R	A	S	T	I	C
Minimum	3.33	6.67	8	8	1	6	4
Maximum	10	10	8	10	10	6	10
Mean	5.6	8.7	8	8.56	9.19	6	5.55
SD	1. 7	1.15	-	0.79	1.62	-	1.44
CV (%)	30	13	-	9	17	-	26

All DRASTIC layers except aquifer media and impact of vadose zone were reclassified by ArcGIS, based on new rates which were calculated using nitrate concentrations. The modified DRASTIC indices were calculated and its map was divided into four classes based on Aller's classification. Figure 2 displays the modified DRASTIC map and nitrate concentrations in the study area. The modified vulnerability map was created in ArcGIS. Correlation between modified DRASTIC index and 15 nitrate concentrations were calculated using Pearson' correlation. Correlation factor considerably increased to 0.84 compared to -0.3 for the original model, as indicated in Table 6.

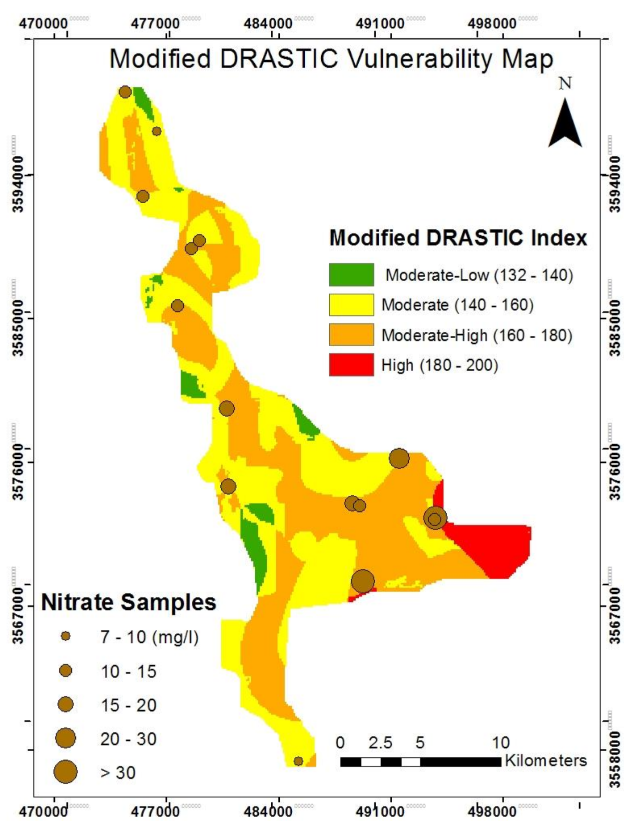

Figure 2: Modified DRASTIC map for the study area

Table 6: Correlation factors between nitrate and modified DRASTIC index

Pearson's correlation coefficient	Number of data	Factor
1	15	Nitrate concentration
0.84	15	DRASTIC index

Figure 6 display the results of Pearson's correlation for the modified and intrinsic DRASTIC models. The values of modified DRASTIC index was obtained much higher than the original DRASTIC indices due to drawback of the original DRASTIC in underestimating the vulnerability level. As the modified DRASTIC map demonstrated the levels of vulnerability in majority of the study area were moderate, moderate-high and high in comparison to the original DRASTIC map with the lower level of vulnerability. It could be concluded that the original DRASTIC underestimated the vulnerability index and modified DRASTIC model significantly performed better in representing the pollution potential (vulnerability) of the study area.

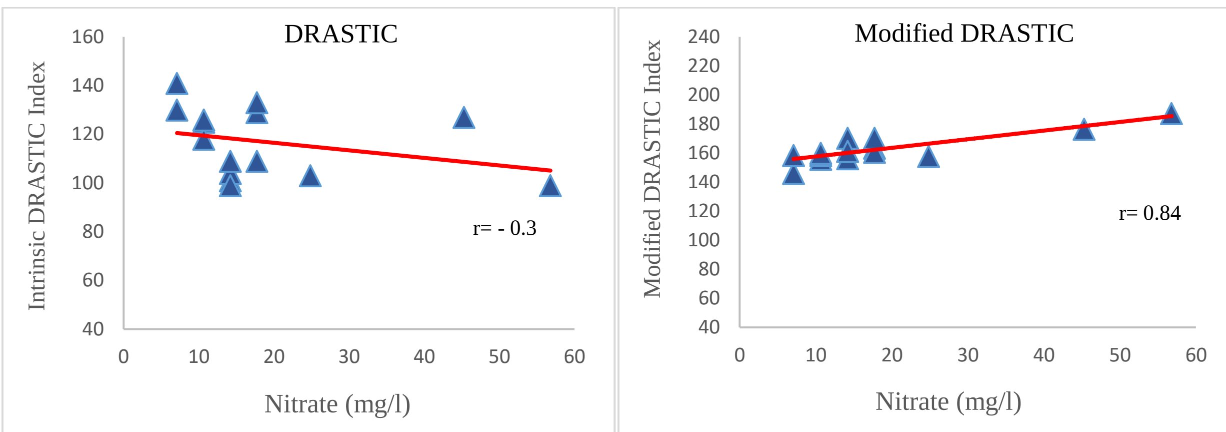

Figure 6: Relationship of intrinsic and modified DRASTIC index to groundwater nitrate concentration for the Shahrekord plain

5 CONCLUSION

The nitrate concentrations in the groundwater can be used as an indicator of pollution due to agricultural activities in the region showing the potential of the leaching of nitrate from the soil surface layers to the groundwater. DRASTIC model was applied as a vulnerability assessment model. Since the original DRASTIC algorithm disregards the effect of regional characteristics, it was modified to obtain more accurate results. Thus, a modified DRASTIC model was developed using the observed nitrate concentrations in the area. The correlation factor between the nitrate concentrations and the original vulnerability index was -0.3, while the correlation factor between the nitrate concentrations and the modified DRASTIC model was 0.84. These results indicated that the modified DRASTIC model significantly improved the performance of the model and provided more reliable results compared to the standard DRASTIC model. The modified DRASTIC model in this study is suggested for assessing groundwater vulnerability to pollution in agricultural lands with extensive use of nitrate. It should be noted that the specifications of area significantly affect the modification method to be applied in the DRASTIC model.

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