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A GIS-Based Study to Investigate Effect of Water Table Changes on DRASTIC Model: A Case Study of Kermanshah, Iran

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Abstract

Groundwater is considered as an important source of water supply in our world. Its contamination is of particular concern as it is a vital source of water for irrigation, drinking and industrial activities. To control and manage groundwater contamination DRASTIC model is a popular approach. This study applied an integrated DRASTIC model using Geographic Information Science (GIS) tool to evaluate groundwater vulnerability of Kermanshah plain, Iran considering water table fluctuation. High fluctuation of water table depth due to wet and dry season in arid and semi-arid areas is notable. The study area is affected by this problem, thus this research investigated the effect of minimum depth water during one year respect to average water depth which is common for this model. Results represent considerable differences for two types of produced maps; map using mean of water table for 5 year and map of minimum water table of one year. Vulnerability maps of mean data classified 40% of the study area as no risk of pollution while this is around 25% for vulnerability maps of minimum depth. In spite, minimum depth vulnerability maps classified around 12% of the study area as moderate risk which is 6% greater than mean depth vulnerability maps. In case of accuracy, results show more correlation between Nitrate data (NO_3^-) and vulnerability maps of minimum water table.

Keywords: Groundwater, GIS, Water Depth, DRASTIC model, Vulnerability.

Introduction

Vulnerability assessment has been applied widely for its sufficiency to delineate areas that are more likely than others to become contaminated as a result of anthropogenic activities at near the earth's surface. These areas can be protected by careful land-use planning, intensive monitoring, and by contamination prevention of the underlying groundwater. Groundwater vulnerability concept was first introduced by (Vrba, Zaporozec et al. 1994) to attract attentions for groundwater contamination. They described aquifer vulnerability as a representing concept of the intrinsic properties of aquifer systems as a function of their sensitivity to human and natural activities. For identifying vulnerable areas, DRASTIC model is a valuable tool that uses basic hydro-geologic variables believed to influence contaminant transport from surface sources to groundwater (Kalinski, Kelly et al. 1994, Rahman 2008). The model generates scored vulnerability maps based on different thematic layers for different locations.

Combined use of DRASTIC with geographical information Science (GIS) was introduced as an effective method for groundwater contamination assessment and water resource management. Many studies applied GIS to improve the results and greatly facilitate the implementation of the sensitivity analysis applied on the DRASTIC vulnerability index (Piscopo 2001, Babiker, Mohamed et al. 2005, Al-Rawabdeh 2013, Yin, Zhang et al. 2013). GIS technique have basically changed management attitudes generally in the area of natural resources and particularly in water resources (Jha, Chowdhury et al. 2007).

While many studies used DRASTIC model but they did not take into account specific characteristic of the study area. For example, (Chitsazan and Akhtari, 2009) applied the model for a semi-arid climate area, in Kherran

Plain, Khuzestan, Iran. The study applied DRASTIC model using GIS successfully but did not considers study area's semi-arid climate. Or (Al-Adamat, Foster et al. 2003) produced groundwater vulnerability and risk-maps using DRASTIC model for the Azraq basin of Jordan with high depth water table. On the other hand, some studies tried to improve the results and considered more parameters or changed parameter's weights etc. , so introduced modified DRASTIC models such as (Fritch, McKnight et al. 2000, Panagopoulos, Antonakos et al. 2006, Denny, Allen et al. 2007, Jasem 2010, Wang, He et al. 2012).

Considering characteristic of arid and semi-arid areas to improve the DRASTIC model results for delineation of vulnerable areas, this study will specifically focus on water depth table parameter of the model. Water depth is considered important because contaminant can reach to the aquifer by moving through it. In other words, shallow water table increases risk of pollution (Baalousha 2006). Studies that applied DRASTIC model to evaluate groundwater vulnerability usually used an average of water table depth as water depth table layer, for example (Babiker, Mohamed et al. 2005) used an averaging data for over a six-year period, or (Chitsazan and Akhtari, 2009) that applied averaging of 5-year period data. But water table depth changes during one year and these changes is too much for arid and semi-arid areas where winter precipitation is often higher than summer precipitation and so the groundwater storage is not fully recharged in summer. Arid and semi-arid areas based on Koppen classification cover approximately 30% of the earth's surface. The objective of this study is to investigate how minimum depth of water table will influence the results of vulnerability maps for arid and semi-arid areas with high fluctuation of water table depth during one year. In this study GIS is greatly facilitate illustration of changes and comparing them.

Study area

Kermanshah Province is located in west of Iran (Figure 1), between 33 04' to 35 17' N and 45 25' to 46 06' E. The study area is located in north and center of the state with area of 850 square meters. It is one of the most important and greatest plains in the area which is mostly agricultural lands. Average height of the plain is 1340m that classifies as moderate height plain. Based on Koppen's classification, the study area allocates to cold, semi-arid climate, with temperature of 12.5 centigrade and average rainfall of 477 mm, annually.

Geologically, Kermanshah plain is part of Zagros Mountains and Gharesoo river pass through the plain. This plain mainly comprises of rangeland and agricultural areas. Geomorphological units are mainly clay, silt-clay and clay-loam. The regional aquifer system is largely unconfined which is the main water resource for local population. Main recharge and discharge to the aquifer is precipitation and pumping respectively. It is an alluvial plain with maximum thickness of 220 meter with mostly 2% slope.

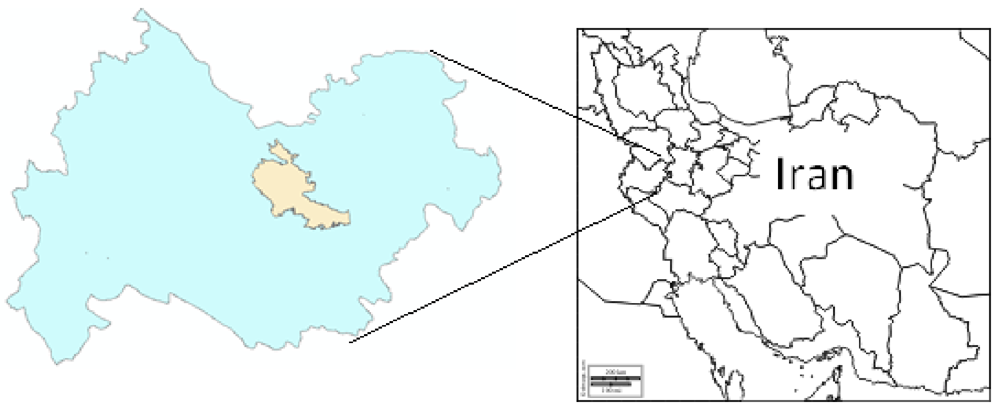

Figure 1: Study area location

Methods and Materials

This study, using GIS environment, applies DRASTIC model to evaluate vulnerability of Kermanshah aquifer. DRASTIC is an index model that combines several thematic layers to map vulnerable locations based on some scores. The original idea of model was to overlay semi quantitative layers manually (Fabbri 1995), that the U.S. Environmental Protection Agency (EPA) developed it to assess potential of groundwater pollution in the United States considering the hydro-geological setting conception (Aller, Bennett et al. 1987). The DRASTIC is an acronym of seven parameters as: Water depth, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity. These parameters are assigned weights ranging from 1 to 5 reflecting their relative importance. Also, the significance of classes or media types rates from 1 to 10 for each parameter, based on their respective effect on the vulnerability of aquifer (Table 1). The DRASTIC vulnerability index denoted DI is determined based on Equation 1. It describes the degree of vulnerability of each hydrogeological unit. The DI is calculated by summing the products of the weight measured from the corresponding parameters according to (Eq.1):

Equation 1

$$DRASTIC\ Index = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W$$

Where D, R, A, S, T, I, and C are the parameters of the model and the subscripts R and W are representative of rating and weights. This index spans the whole range from 23 to 230 (H. Elfarrak 2014). The numerical ratings and weights were established using the Delphi technique and are well defined. This makes the model suitable for producing comparable vulnerability maps on a regional scale (Aller, Bennett et al. 1987).

Sensitivity of aquifer and mapping vulnerability of groundwater is applied in this study with the use of a Geographic Information Science (GIS). For mapping vulnerability, GIS has been known as a popular and helpful tool where its capability for manipulating and analyzing of spatial based information is proved. Although, the DRASTIC model was not designed for GIS-based application at first, but its compatibility with GIS is demonstrated (Merchant 1994).

Table 1: The DRASTIC Weights and Ratings (Aller, Bennett et al. 1987)

Water depth table (m) (weight=5)		**Net Recharge (mm year−1) (weight=4)**	
0-1.5	10	178–254	8
1.5–4.6	9	102–178	5
4.6–9.1	7	51–102	3
9.1–15.2	5	<51	1
15.2–22.9	3		
22.9–30.5	2		
>30.5	1		
Aquifer media (weight=3)		**Soil media (weight=2)**	
Sand and gravel	8	Sand dunes	9
Sand with some clay/silt	6	Loamy sand to sandy loam	6
Clay and silt with some sand/gravel	4	Silty-clayey loam to clay loam	3
Clay and silt	2		
Topography (slope %) (weight=1)		**Impact of vadose zone (weight=5)**	
0–2	10	Sand	8
2–6	9	Silty sand	7
6–12	5	Clayey sand	6
12–18	3	Sandy silt	5
>18	1	Sandy clay	4
		Silty clay	3
		Confined aquifer or compact clay	1

Preparation of the parameter maps

Water Depth: the distance from the ground surface to the water table, the surface beneath ground level where all pores are filled with water, is defined as water Depth. It is considered important because water depth relates to travel time for contaminant to reach water table; where shallower water levels means shorter travel times and higher risk of vulnerability as the water depth decreases. (Chitsazan and Akhtari 2009).

Water table depth changes during year and these changes may be too much for some study areas where winter precipitation is often higher than summer precipitation and so the groundwater storage is not fully recharged in summer. Monthly information of water table depth in our study area shows there is a remarkable fluctuation in water table depth during one year. For example, one station in the study area experienced 15.2m difference in ground water level where it varied from 27.1m in low precipitation season to 11.9m in high precipitation season. The average fluctuation of water table in the study area was 5.58m in 2011. Considering this fluctuation will definitely effect on final result of vulnerability. Since this fluctuation occurs in many places, so, this study will compare the results for minimum and average water level and the changes they may cause.

For preparing the water depth table layer, data for 66 piezometers were considered. Two types of water table depth were produced based on using average or minimum data.

Mean water depth of 5 years from 66 piezometers were used for creation of this layer (2006-2010). (Figure 2) shows mean water depth.

Minimum water depth for this layer, monthly information of depth water for each year was used. Minimum of depth water among 12 months for each piezometer were selected as water level of that piezometer. So, 5 different water depth layers were produced, each year has one water depth layer which represents minimum water depth experienced during that year. (Figure 2) shows results of year 2010 as an example of minimum water depth layer.

To avoid confusion and redundancy, vulnerability maps produced based on the mean data is called M-map and the other five vulnerability maps based on minimum depth of water table of each year are named as A, B, C ,D and E maps for years of 2010, 2009, 2008, 2007 and 2006, respectively.

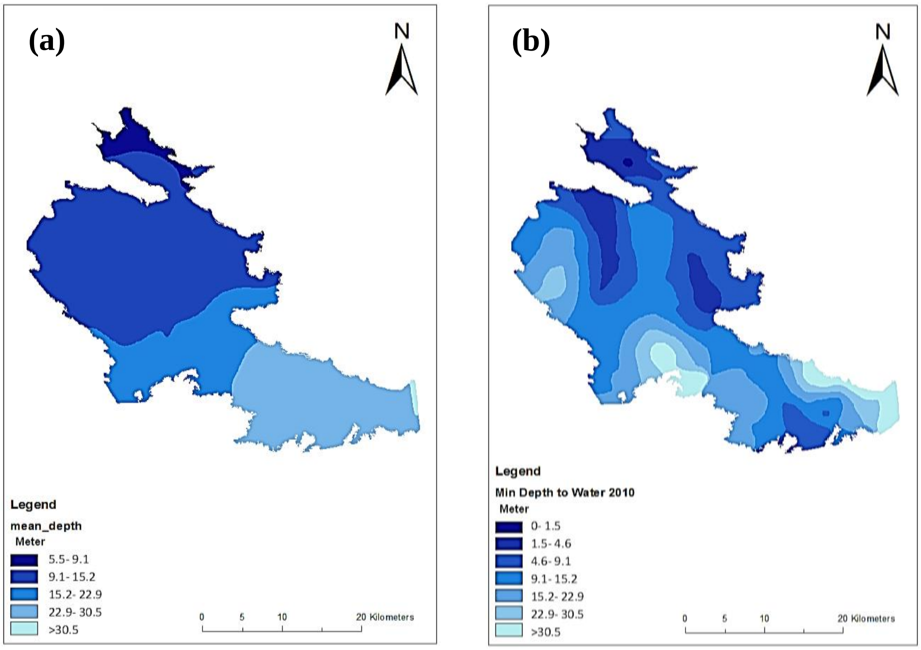

Figure 2: Water depth table. (a) Shows mean depth of water table for 5years. (b) Shows minimum depth of water for year 2010

Net recharge: the quantity of water per unite area of land which infiltrates from the ground surface to the aquifer annually. The recharge water is one of the resources to transport contamination (Saro 2003). So considering its importance, Piscopo method (Piscopo 2001) was used for preparation of the net recharge layer:

Recharge Index = Slope (%) + Rainfall + Soil permeability

Aquifer media: is an underground rock unit that will yield sufficient amount of water. Aquifer media includes fractures and pore spaces of the media that holds water, so it affects the flow within the aquifer. And, the rate of pollution contact within the aquifer is controlled by this flow path (Aller, Bennett et al. 1987). The aquifer media layer for the study area was prepared using information from 57 well loges. It was rated and then weighted based on Table 1.

Soil media: quantity of recharge water that can pass through into the ground significantly depends on soil, and consequently moving of contaminant into the vadose zone is affected. Soil map of study area is produced by Natural Resource Organization Office of Kermanshah Province, with scale of 1:750,000,000. According to this map layer, least permeability of the study area is rated as 3 where texture is silt-clayey loam; rate of 6 assigned to central part that its texture is loamy sand to sandy loam and the highest permeability with rate of 9 is allocated to areas of sand dunes.

Topography: in DRASTIC model, topography is defined as slope. For preparation of this layer, topographic map of the study area with scale of 1:25000 were used to generate a 5 meter digital elevation model (DEM), then using produced map slope layer derived and based on DRASTIC model criteria's classified.

Impact of vadose zone: unsaturated or discontinuously saturated zone above water table is defined as vadose zone. Its type is important to distinguish the attenuation of material characteristics above water table. Moreover, this zone controls the path of polluted particles to the aquifer system. The vadose zone media layer in our study area was derived from litologic data of wells and logs of 57 piezometers.

Hydraulic conductivity: due to lake of information this study did not use hydraulic conductivity layer and it causes that ranges of DRASTIC Index change to 20-200

Results and discussion

DRASTIC vulnerability Index

Six different depth-to-water-table layers were produced; one layer for mean of 5 years and the other five layers according to minimum water depth of the study area experienced during one year. Based on these six layers, six different vulnerability maps were created. All data layers were produced in ArcMap environment and in raster format. Values of each pixel, which was derived based on DRASTIC model weighting criteria, was summed for overlaying while it was multiplied by DRASTIC rating scores. Then produced index range classified into for classes of; no risk, low, moderate and high potential of vulnerability risk. The final index values ranges from 20 to 200 (Table 2) where the higher DRASTIC index value, the greater the relative groundwater contamination potential. The maximum DRASTIC value for M-map is 148 and the minimum is 33, while maximum and minimum DRASTIC values for yearly maps vary between 158 and 33.

Table 2: The DRASTIC index for the study area

DRASTIC Index	DRASTIC Range
No Risk of pollution	<70
Low potential	70- 105
Moderate potential	105- 140
High potential	>140

The generated DRASTIC vulnerability maps (Figure 3) in general represents no or low vulnerability risk for most part of the study area. The highest vulnerable area, based on the results, is northern part which is mainly in moderate risk of pollution. If considering water depth table map (Figure 2), it is clearly obvious that there is relation between water depth and risk of pollution where in northern part less water depth leads to more risk of pollution. This correlation can easily be noticed between minimum water depth table map and its vulnerability map (Figure 2 b and Figure 3 A-Map) rather than mean water depth table and mean vulnerability map (Figure 2 a and Figure 3 M-Map). This comparison shows areas where water depth is less than 4.6 meter are classified as high risk of contamination in A-Map (Figure 3).

On the other hand, mutual comparison of M-map, which is generated based on mean of one year of water depth, and the other maps show there are obvious differences. In M-map data 94% of the total area is classified as No and Low risk of pollution, while this area is 87% for A-map and even 81% for E-map. It means maps of yearly data (A, B, C, D and E) classified greater areas with higher potential of pollution. Specifically, in classification of moderate area there is 3 to 12 percent difference, where in E-map 18.5% of the total area is classified as moderate risk but M-map just considers 6% of the area with moderate potential of pollution. In brief, these data demonstrates water depth changes directly influences the vulnerability map and mean data just dampen results.

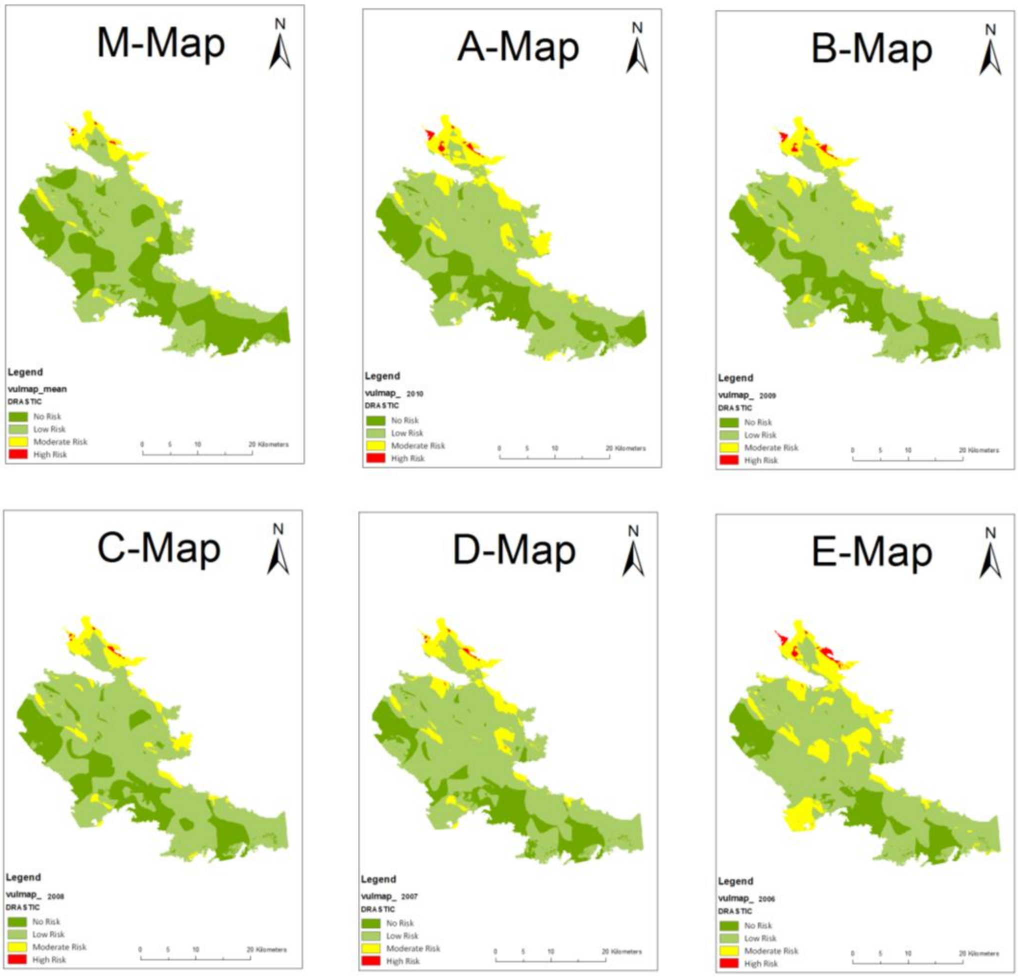

Figure 3: The six DRASTIC aquifer vulnerability maps. M-map shows vulnerability map produced using average of 5 years of water depth data, A, B, C, D and E-maps are vulnerability maps based on minimum water depth data for years 2010, 2009, 2008, 2007 and 2006 respectively.

Table 3: Area percentage of the study area for six DRASTIC vulnerability maps

	M-Map		A-Map		B-Map		C-Map		D-Map		E-Map	
	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
No Risk	330	39	217	26	232	27	213	25	178	21	141	17
Low Risk	466	55	518	61	537	63	563	66	581	68	544	64
Moderate	52	6.125	107	12.6	76	8.9	72	8.5	89	10.47	157	18.5
High Risk	1	0.118	5	0.59	5	0.59	2	0.24	2	0.24	7	0.83

Discussing percentages of areas and how they differ is so helpful for understanding statistics but the main and important question is about location of differences to define protection area. Considering this point, north of the study area seems is the most vulnerable area based on Figure 3 and this part of the study area has main changes in classification of high risk area. Also, some areas in east part of study area have high risk of pollution which is not considered in M-map. Figure 4 (a) shows areas that are classified as high risk in A-map and is not considered in M-map. There is the same difference for the moderate risk of pollution area that M-map does not consider them as moderate potential risk area.

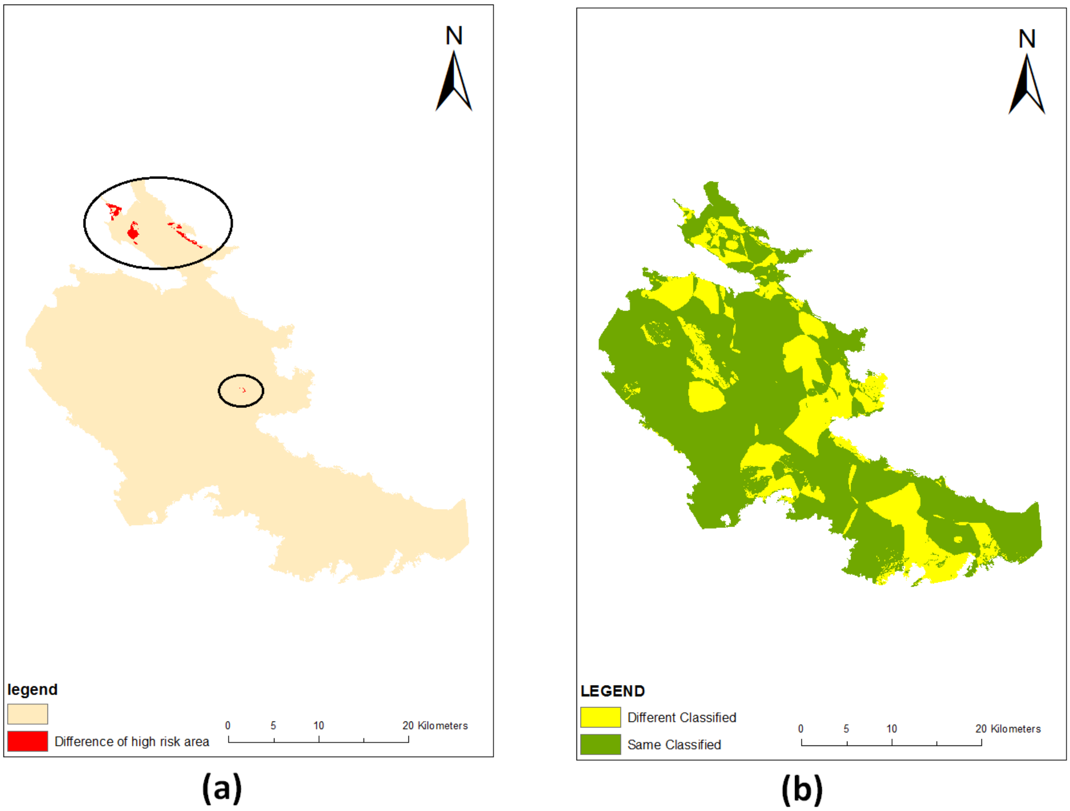

Figure 4 (a) difference map for High Risk class, it shows high risk areas in A-Map which is not classified in M-Map (b) map of same and different classified areas in M-Map and A-Map

In case of similarity of results and produced map, comparing M-map and A-map shows that only 73% of the area is classified the same for both maps and around one third of the study area is classified differently. These differences as Table 3 represents are remarkably in the no risk and moderate classes, where no risk class in M-map covers around 40% of the study area and it decreases to approximately 20% for yearly data. By decreasing the no risk area in yearly maps, the moderate risk of pollution area increases to around 12% where it is 6% in M-map. These changes mean using average data of water depth table effects seriously on final DRASTIC map. Figure 4 (b) represents same and different classified areas which are mostly vulnerable area.

Validation of Results

Usually vulnerability maps illustrate potential expectation of an aquifer to be polluted, in order to have reliable overview the results of vulnerability mapping of every worked out index must be validated to show the degree of accuracy of the index. Groundwater bodies exposed to different types of pollution contain nitrate, rascal bacteria and eventually human medical residues. Groundwater bodies vulnerable to agricultural and irrigation activities may contain biocides, fertilizers and other specific pollutants. Considering situation of study area which the main part is covered by agricultural lands and the most common fertilizers are nitrate or animal mucks, only nitrate anion(NO_3^-)was analyzed to validate the groundwater vulnerability results.

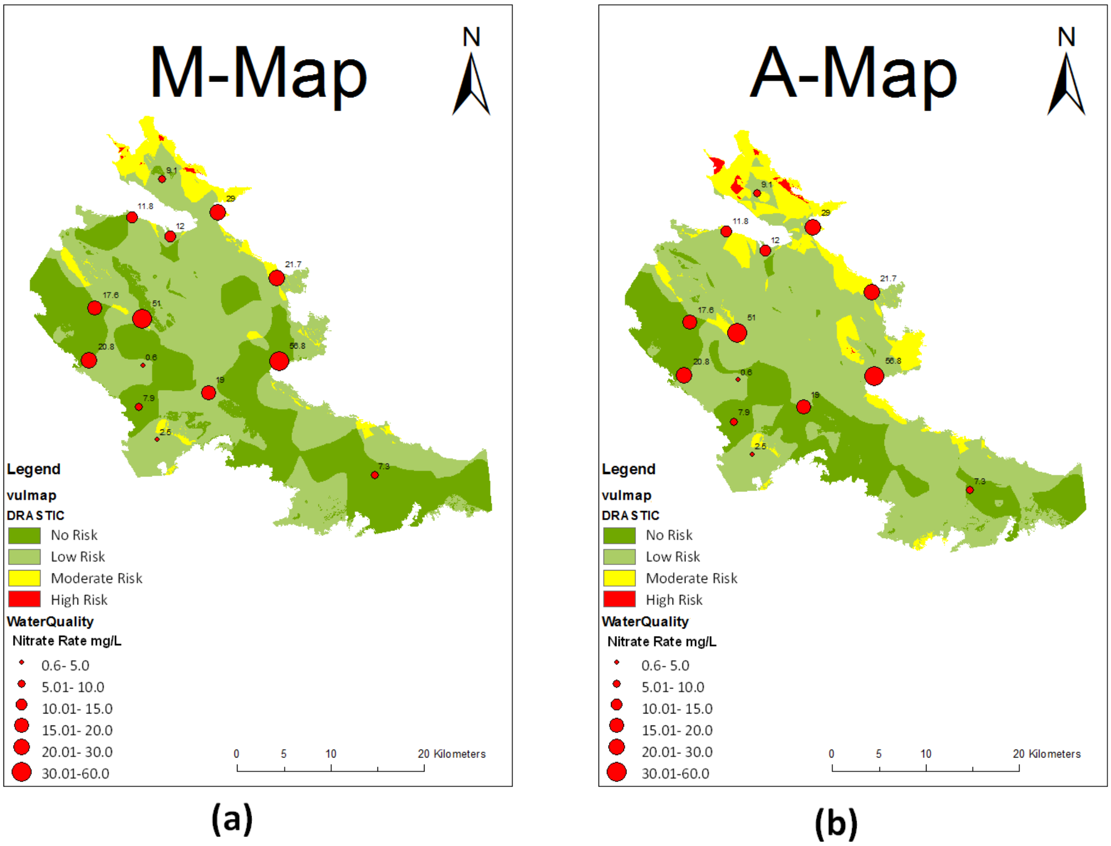

Figure 5: Location of wells and nitrate concentration in groundwater at the study area

14 agricultural wells were used for collecting water samples and these data were used to analyze and evaluate the result maps. Data was collected and prepared by Kermanshah water & wastewater Company. Dou to less number of water samples, producing contour line map of sample data or grid map does not provide reliable results, so the distribution of NO_3^- concentration, which ranged from 0.6 mg/l up to 56.8 mg/l, is shown as point data map in Figure 5. The highest value of NO_3^- is located on eastern part of the study area that has moderate risk of polution and the lowest values generally are in no risk areas. Comparing NO_3^- concentration with five yearly vulnerability maps shows that these map provided more reliable results respect to M-map, where in eastern part of study area that are classified as moderate risk in yearly maps there is high value of NO_3^- (56.8) but M-map classifies this area with no risk of pollution. There are some examples in western part of the study area with approximately high NO_3^- value that is depicted better in yearly maps than M-map. Better comparison can be seen in Figure 5.

Conclusion

Improving DRASTIC model has been done by many studies and it was introduced as modified DRASTIC. This study considers specific characteristics of some study areas to improve DRASTIC vulnerability maps. One important parameter of DRASTIC model is the water depth table with the highest weight which shows its role in final vulnerability map. This study used monthly information of piezometers to extract the minimum water depth of each piezometer during a year and then used this minimum data as water depth table layer instead of average data. The objective of this study is 1) to demonstrate the importance of minimum water depth in depicting vulnerability maps and 2) to represent differences of vulnerabilities locations using GIS. Comparing vulnerability maps of average and minimum data shows that using average data cause to classify high percentage of the study area as no risk of pollution (around 40%) while using minimum data leads to identify greater areas as moderate and high potential of pollution.

Evaluation of results with nitrate data (NO_3^-) reveals better correlation between vulnerability maps of minimum depth of water rather than maps produced by average data. So, for areas with great fluctuation of water depth (arid and semi-arid areas in particular) it is better to use minimum water depth in year instead of average of several years to get more reliable and accurate vulnerability maps. Providing trustworthy and valid vulnerability maps will help to contrive a careful land-use planning and intensive monitoring for protecting groundwater contamination.

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