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Studying and Assessment of Vulnerability and local changes of Quality of Karaj plain Aquifer with DRASTIC Method

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ABSTRACT: Vulnerability assessment of aquifer is very useful for development, management and land use decisions, monitoring the quality of groundwater resources and preventing pollution of this water. Aquifer system, naturally, is able to reduce the effects of pollution and wouldn't be easily exposed to pollution but in the event of contamination, it is very difficult to remove it from the contaminated environment. The replacement cost of a local contaminated aquifer is really high and the loss of it will also lead to contamination of other water resources in the region. Therefore in developing countries it is practically impossible to revive the aquifers. So it seems very necessary to identify the most vulnerable aquifers to damage. One of the suitable ways to prevent groundwater from contaminating is identifying the most vulnerable points of aquifer and managing the land. In this paper, according to the hydrological and hydrogeological characteristics of the area under study, aquifer vulnerability to contamination potential, zoning can be. The purpose of this study is to assess groundwater pollution in Karaj plain using DRASTIC model.

Keywords: Vulnerability, Aquifer, Karaj Plain, DRASTIC Method

INTRODUCTION

Groundwater pollution is diagnosed after the contamination of drinking water wells at the time that it is almost impossible to eliminate the contamination of groundwater; therefore, protecting water quality and scanning aquifer vulnerability are of significant importance. In areas where drinking water comes from underground, it is very important to evaluate the quality of these waters [1].

Ground water is among the most important natural resources in the world, at present, a considerable part of the water consumption of the country of Iran, especially drinking water, is provided by groundwater resources. Lack of proper recognition or non-recognition of the quick vulnerability of underground waters may cause serious pollution of these resources, and it may even happen that the polluted resource can no longer be used and lots of time and expense should be spent to eliminate the contamination and reuse it. Recent human activities have created a vulnerable environment up to the point that the ground water, as a natural resource, has been exposed to industrial pollutants [2].

The concept of vulnerability has been presented for the first time in late 1960 in France for awareness about groundwater contamination. Groundwater vulnerability means possible penetration and distribution of pollutants from the surface into the underground water system [3].

The vulnerability could be defined as penetration and distribution of contaminants from the surface to the groundwater system. Aquifer vulnerability shows its power of penetration and distribution of contaminants from the surface to the groundwater system, so that the pollution formed on the surface of the water can reach the groundwater and spread in it [4].

Vulnerability is a relative, dimensionless and non-measurable characteristic that depends on the aquifer features, geological and hydrogeological environment. Various methods have been proposed to assess the vulnerability of groundwater that can be divided into three groups of processing, overlap and statistical methods [5].

In processing methods, simulated models are used to estimate the movement of pollutants. Statistical methods use correlation between the location variables and extent of contaminants in groundwater. Index_ overlap methods integrate motion controller parameters of contaminants from the surface of the ground to saturated zone and determine an index in different parts of the region, called the vulnerability [6].

In index-overlap method, selecting the numerical value of the parameters is somehow expert and these methods cannot be used as an accurate prediction method. However, the simplicity and ease of preparation of their required information in regional scale on one of the major advantages of this method [7].

DRASTIC method uses seven parameters including depth of groundwater, recharge, aquifer environment, soil type, topography, the effect of the unsaturated region and hydraulic conductivity to zone aquifer vulnerability [8].

Using DRASTIC method and geographic information system, a map of groundwater vulnerability for various areas has been prepared including the area of Zhang Ji of China [9], aquifer Kakamygahara in Japan, [10], and also in Iran aquifers such as Khash plain aquifer, [11], Jovin plain Aquifer [12].

Abbasi and Mohammadi (2013) have assessed and prepared the pollution vulnerability map of karst Mansht aquifer using risk model. The results of the above survey show the high effectiveness of the risk model to study the vulnerability of karst water resources. In this regard, management factors, such as closed holes and preventing contaminants to enter into the area, preventing the destruction of forests, hydraulic calculations and determination of aquifer boundaries were proposed for management actions [13].

Mahmoodzadeh *et al.,* (2012) analyzed the sensitivity of Meymeh groundwater vulnerability using DRASTIC method. The results of the above survey showed that the internal vulnerability potential for Meyme aquifer is in low and medium range and results of this model which is almost the most complete indicator to assess the vulnerability potential of the groundwater have estimated the low vulnerability as 44.76% and the middle range as 55.24 [14].

Arezoomand Omidi *et al.,* (2014) assessed the vulnerability of groundwater using standard and hierarchical DRASTIC methods. The results of the above survey showed that hierarchical DRASTIC method showed the vulnerable areas much better; so that in hierarchical DRASTIC map 9.7 percent of the plain is highly contaminated, but in standard DRASTIC map 0.0008 of the plain has this condition [15].

Kaveh *et al.,* (2013) assessed the vulnerability of ASTANA-Kuchesfahan aquifer using two methods: GOD and DRASTIC. The results of the above survey showed that in DRASTIC method most areas are in the middle and high range, while in GOD method, poor and low range areas are more extensive [16].

Sajjadi and Mozaffarizadeh (2014) assessed the vulnerability of Borazjan plain aquifer using DRASTIC method. The results of the model show that 8.5% of Borazjan aquifer has very high, 9.2% high, and 38.9% moderate to high, 31% moderate and 12.4% low contamination potential. South-western parts of the region have higher potential for contamination than other parts of the plain [17].

In this study in order to identify vulnerable areas of Karaj plain aquifer to pollution and prepare the aquifer vulnerability map DRASTIC method is used. First, plain sensitivity map for each of the models as been prepared according to the information layers including aquifer range, the saturation part, depth of hydrostatic, aquifer recharge, soil condition, hydraulic conductivity, topography and land use, then using DRASTIC method, risk maps of groundwater pollution will be produced. In summary, the purpose of this study is zoning the vulnerability of Karaj aquifer using DRASTIC method.

MATERIAL AND METHODS

DRASTIC method has been offered by the US Environmental Protection Agency as a standardized system for evaluating the vulnerability of groundwater resources against contamination. The first purpose of DRASTIC method is applying and implementing emergency activities regarding groundwater. Also providing a practical tool for assessing the vulnerability of groundwater against pollution is another aim of this method.

A. Vulnerability of descriptive rating with DRASTIC model

Acronym DRASTIC stands for parameters that control ground water pollution in hydrogeological system and include:

-Groundwater depth (D)
-Net Recharge (R)
-Material of the aquifer (A)
-Soil type (S)
-Topography (T) -Effect of Unsaturated Zone (I)
-Hydraulic conductivity of the aquifer (C)

B. Weightings with DRASTIC model

For each of seven Drastic parameters, and according to the importance of each of them in vulnerability, a weight of 1 to 5 will be assigned. The most important will have five and the least important will get 1. Table 1 shows assigned weights to seven DRASTIC parameters.

C. Grading With DRASTIC Model

Each DRASTIC parameter is assigned a value of 1 to 10 according to their position in the mentioned range (Table 2).

Table 1. Weights assigned to seven DRASTIC parameters.

Parameter	Weight
Groundwater depth (D)	5
Pure recharge (R)	4
Material of the aquifer (A)	3
Soil type (S)	2
Topography (T)	1
Effect of unsaturated zone (I)	5
Aquifer hydraulic conductivity(C)	3

Table 2. Ratings and ranges of groundwater depth.

Ground water depth (m)	
Range	**Ranking**
1.4-0	10
4.5-1.5	9
9-4.6	7
15.1-9.1	5
22.7-15.2	3
30.3-22.8	2
> 30.4	1
Weighting: 5	

Table 3. Ranges and ratings of pure recharge.

pure recharge (mm)	
Range	**Ranking**
50.7-0	1
101.5-50.5	3
177.7-101.6	6
253-177.8	8
>254	10
Weighting: 4	

Table 4. The topography ranges and ratings.

Topography (slope)	
Range	**Ranking**
1.9-0	10
2.5-2	9
11.9-6	5
17.9-12	3
>18	1
Weighting: 1	

Table 5. Ranges and ratings of the aquifer's hydraulic conductivity.

Hydraulic conductivity (m/ day)	
Range	**Ranking**
4-0.04	1
12.2-4.14	2
28.6-12.3	4
40-28.7	6
81-41	8
> 82	10
Weighting: 4	

Table 6. Ranges and ratings of the saturated environment of aquifer.

Aquifer environment	
Range	**Ranking**
Shale mass	2
Igneous / metamorphic	3
weathered Igneous / metamorphic	4
Moraines	5
Layers of sandstone, limestone and shale sequences	6
Massive sandstone	6
Massive limestone	8
Sand	8
Basalt	9
Karst limestone	10
Weighting: 3	

Table 7. The unsaturated zone range and ratings.

The aquifer environment	
Ranking	**Range**
1	Enclosing layer
3	Silt / clay
3	Shale
6	Limestone
6	Sandstone
6	Sandstone, limestone and shale layers
6	Sand with plenty of clay and slit
4	Igneous / metamorphic
8	Sand and gravel
9	Basalt
10	Karst limestone
Weighting: 5	

Table 8. Ranges and ratings of the soil.

The aquifer	
Ranking	**Range**
10	Thin layer or lack of soil or
10	Gravel
9	Sand
8	Peat
7	Compacted / or dense clay
6	Sandy loam
5	Loam
4	Silty loam
3	Clayey loam
2	Muck
1	Non-compacted clay
Weighting: 5	

RESULTS AND DISCUSSION

Zoning of the vulnerability has been done at GIS. For this purpose, statistics and information has been entered into a GIS database, respectively. In this study various information sources have been used such as: topographic maps with a scale of 1: 50,000 (Army Geographical Organization), geological maps at a scale of 1: 100,000 (GSI), soil map (Institute of Soil and Water), Meteorology statistics, hydrology, surface of groundwater, pumping tests results, drilling log of observation exploration and exploitation wells, geophysical maps and statistics of resources and water uses from the regional water organization. Map data (like topography and soil maps) have been digitized and entered into a GIS database and table data (groundwater level) were altered to database format and entered into a database.

Vulnerability assessment using DRASTIC method: Depth of groundwater (D): This parameter determines the depth that pollution should go through to reach the water table and it is very important. Usually damping capacity increases to the water table level with depth increase, because the lower the level of the water is, the movement and possible remediation of pollution will increase. Statistics about the depth of groundwater comes from drilled observation wells in aquifer experience. Using monthly depth access of water levels in observation wells of Jovein plain and verifying the data and if necessary, correcting them, using Spline method, the map of water depth has been provided.

Net recharge (R): Net recharge is the amount of water that penetrates from the surface and reaches the water table. Recharging groundwater causes the pollution to move vertically and reach the water table and then move horizontally in the aquifer. This parameter controls the volume of water that can cause dispersion and dilution of contamination in saturated and unsaturated zones. Usually the more the recharge is, the more will be the contamination potential of ground water. It is normal if the recharge is too low, the risk of pollution is reduced. Jovein groundwater recharge resources are: recharge from precipition, recharge from runoffs and surface flow, wastewater back into the groundwater from agricultural, domestic and industrial use. Therefore net recharge (total recharge) is obtained from the sum of them.

The aquifer environment (A): An Aquifer environment describes the damping characteristics of the aquifer material components. This feature reflects the dynamism of pollution in the components of the aquifer. Information about Joe in plains aquifer is obtained from subsurface explorations (log exploratory drills, piezometers and exploitation wells), geological and geophysical exploration of the area. In Jove in plain, location map of exploratory drill log has been provided with precise observation and characteristics of the aquifer have been valued based on exploratory surveys according to the standard method of DRASTIC.

Soil type (S): Soil layer of about 5.0 to 2 m thick is usually very active in the area of microbiology. Due to the high microbial activity in the soil, high organic matter and roots of plants, it has high potential to remove pollutants and reduce the concentration. In this study, soil map of the area which was prepared by the Institute of Water and Soil has been digitalized.

Topography (T): Topography controls motion of pollution and keeping it on the surface. Low slope at ground level will cause the slow movement of pollutants and gives them more chance to penetrate. Therefore, the gentle slope creates a greater potential for groundwater contamination. Also topography influences the spread of soil and therefore the damping of pollution.

In jovein for preparing the slope map, digital maps of army geographical organization have been used with a scale of 1: 50,000. For this purpose, topographic maps in ArcGIS software were converted to a digital elevation model and then the slope map was calculated and derived from digital elevation model.

The effect of unsaturated zone (I): The effect of unsaturated zone expresses the damping characteristic of component materials of aquifer in the unsaturated part and it is of great importance in vulnerability assessment. How to obtain information about the unsaturated zone model is similar to aquifer environment except that in this case the characteristics and granting of sediment between groundwater and surface level will be taken into consideration.

Hydraulic conductivity (C): This parameter describes water conductivity and water-soluble contaminants. The data of hydraulic conductivity is gained through calculations of pumping test. In areas that pumping test hasn't been done yet, based on the sample values and similar structures, the type and texture of the sediments forming the aquifer, hydraulic conductivity will be estimated. In this research the hydraulic conductivity map has been extracted from the results of mathematical model of Jovein groundwater.

Vulnerability mapping with DRASTIC method. After preparing the required parameters for vulnerability assessment using DRASTIC method, Vulnerability mapping was began to be prepared. In this method by combination of seven parameters, vulnerability index is gained according to Equation (1) where r is the classified value of each parameter and w is the weight of each of the parameters.

Index = DrDw + RrRw + ArAw+ SrSw + Trw + IrIw + CCw(1)

A. DRASTIC Vulnerability

Classification and valuation of different classes for each parameter has been done according to the standard method of DRASTIC (Aller et al., 1987), In GIS. Each parameter is assigned a DRASTIC model and based on the importance of each of their vulnerability a weight of 1 to 5 will be given. The most important will get 5 and the least important ones will have 1. Combining these parameters, a map will be obtained that shows the internal vulnerability of groundwater against pollution in individual cells as a spectrum of color.

By integrating of the parameters according to equation 1, the result will be a network layer in which cells with higher numbers indicate regions where the internal vulnerability of groundwater against pollution is more; and the cells with lower numbers are areas with less internal vulnerability of groundwater against pollution. In DRASTIC model, the final index is obtained from ranked numerical values of each parameter multiplied by the weight of that parameter. For example, groundwater depth parameter is assigned 5 and the numerical value of different levels of the groundwater will vary from 1 to 10. So DRASTIC index of water depth parameter will vary from 5 to 50. Likewise, recharge parameter from 4 to 40, the aquifer environment from 3 to 30, soil type\ from 2 to 20, topography from 1 to 10, the effect of the unsaturated area from 5 to 50 and hydraulic conductivity from 3 to 30 will vary.

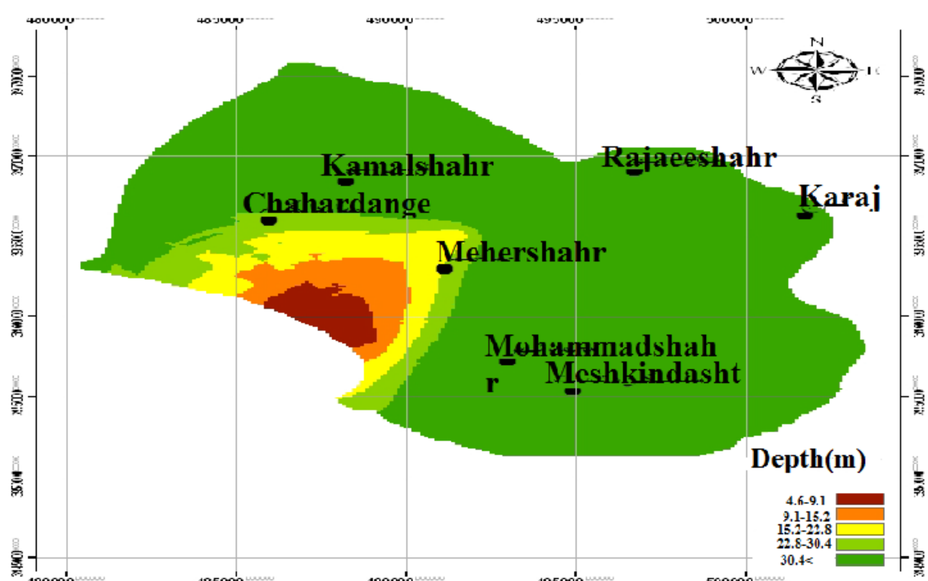

Fig. 1. The range of changes in groundwater depth of Karaj aquifer.

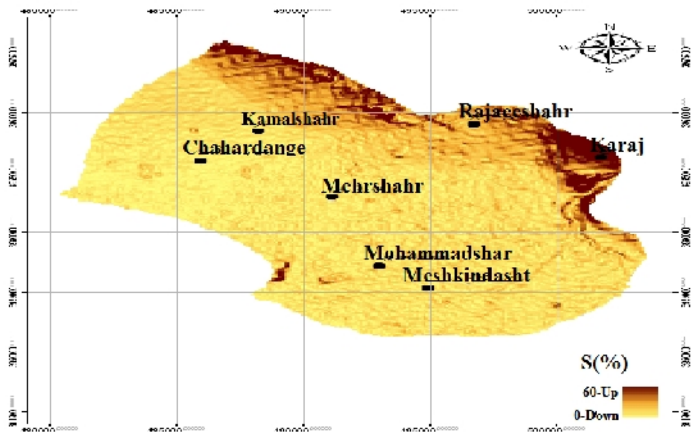

Fig. 2. The slope percent of Karaj aquifer.

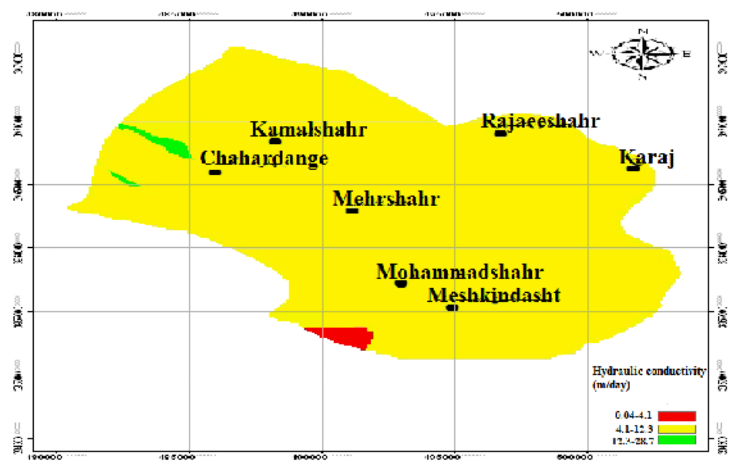

Fig. 3. Range of changes in soil hydraulic conductivity of Karaj aquifer.

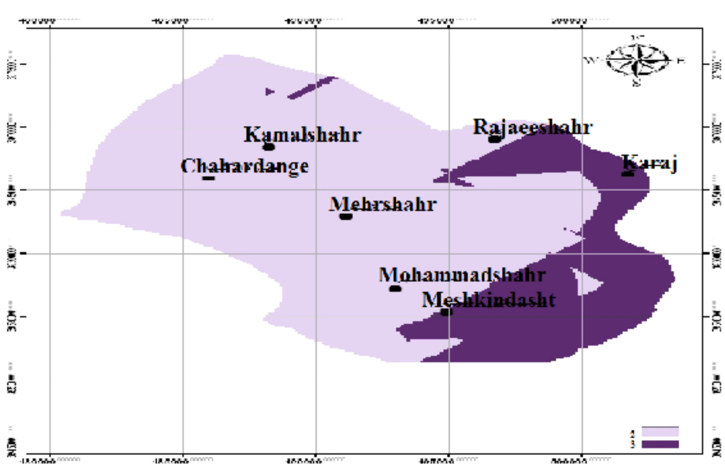

Fig. 4. Ranking the saturated zone of Karaj aquifer.

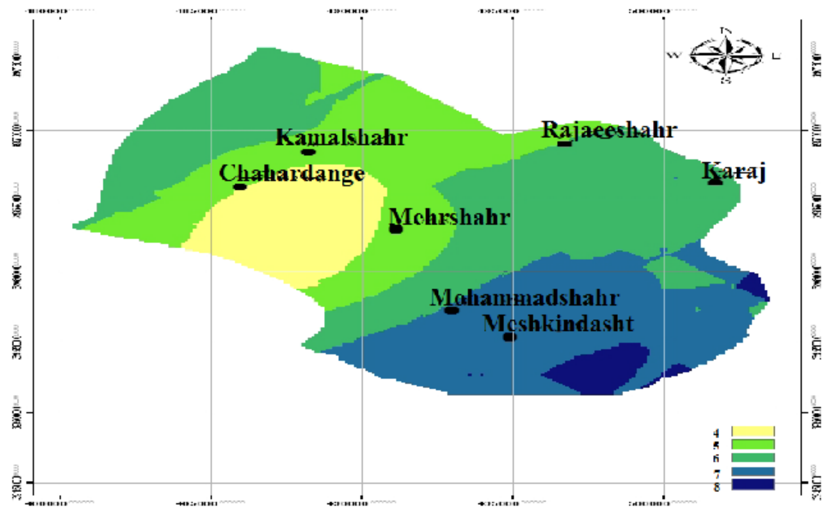

Fig. 5. Ranking the unsaturated zone of Karaj aquifer

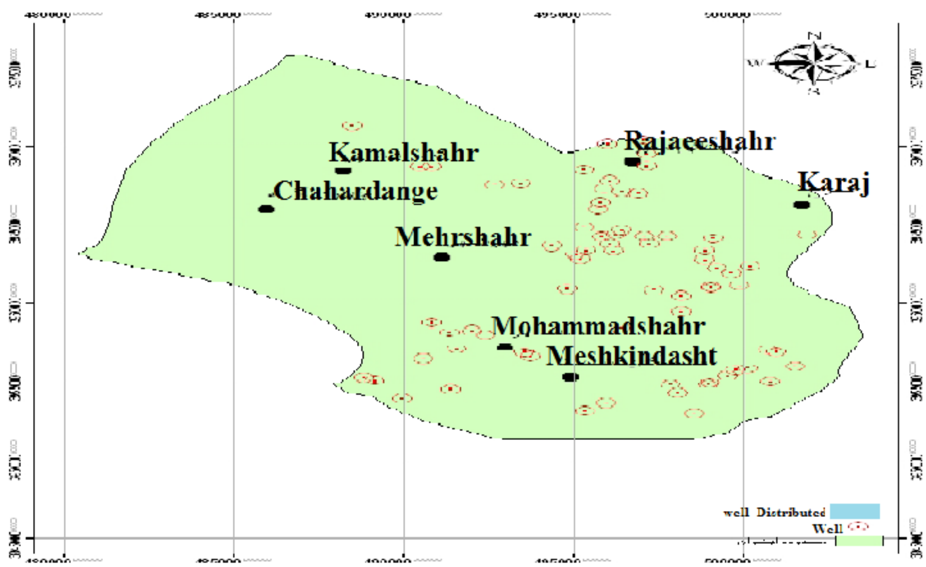

Fig. 6. Position of sampled wells in Karaj aquifer.

Lead levels in Table (9) will be classified as follows:

Table 9. Classification of lead levels.

Pb (mg)	Ranking
0.2 - 0.47	Poor
0.48 - 0.53	Low
0.54 - 0.58	Average
0.59 - 0.62	High
0.63 - 0.8	Very high

SUMMARY

The areas with high vulnerability should be classified as critical or high risk areas in final map of quality boundary of aquifer. Map of quality boundary is classified to four parts of safe, low-risk, dangerous and critical. It should be noted that the number of classes depends on the work required and sensitivity, so that it is possible to increase or decrease the number of classes. Increasing class show more details and excessive reduction of classes (2 or 3 classes) decreases the accuracy of the maps. It is important to note that the classification of these maps is relative, meaning that the class only shows the type of aquifer boundaries of an area other compared to another one. According to the above shapes regions with high vulnerability or industrial use have higher risk. In other words, using this map, quality boundaries of the region is specified considering vulnerability and pollution.

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