

Monitoring Kuhdasht Plain Aquifer Using the Drastic Model (Water Quality Index of the US National Institutes of Health) In the GIS Environment

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ABSTRACT: Identification and provision of zoning of vulnerable aquifers, i.e. areas where pollutants can penetrate and distribute from ground surface to groundwater system, is an appropriate management tool to prevent the contamination of groundwater resources. There are several methods to assess the vulnerability of aquifers, which are generally divided into three main groups: statistical methods, mathematical methods, and overlapping indexes methods. In this research, due to the importance of plain aquifer for agricultural and drinking water supply of the region, drastic method is one of the most applicable overlapping methods used. The plain aquifer vulnerability map derived from the combination of seven raster maps of drastic model parameters (water table depth, pure supply, aquifer type, soil type, topographic slope, non-saturated environment ingredients and hydraulic conductivity) is used; it has been developed in seven layers in ArcGis software. The final aquifer vulnerability map was prepared for contamination by weighting and ranking and combining the seven layers above. Matching the nitrate ion on the final drastic map, it was determined that all points with high nitrate are in the high contamination range, approving the accuracy of the model. According to the zoning map obtained, about 0.98%, 12.98%, 62.56%, and 23.48% of the study area were within the low, moderate, moderate to high, and high vulnerability ranges, respectively. The results of this study indicate that the highest vulnerability potential is in the moderate to high class, and the northern, northwestern and western areas of the plain have a high potential, while the southwest areas have the lowest potential.

KEYWORDS: Vulnerability, Drastic Model, Groundwater, Kuhdasht Plain

I. INTRODUCTION

The increasing development of human societies and the expansion of industrial activities have a major contribution to environmental pollution, especially water (Rahman 23: 2008). Therefore, human activity in some cases affects the balance of existing capacity in nature. (Konudal et al., 423: 2007)

Aquifers are one of the most important water sources vulnerable to contamination. These sources are exposed to contamination in various forms, making it more difficult and costly to detect and control contamination compared to surface water. Also, due to the continuing contamination in these sources, the polluter and vulnerable sources, it is appropriate to prepare vulnerability zoning maps and adopt management policies. (Konudal et al., 235: 2007) (Biker et al., 130: 2005)

The concept of vulnerability was first introduced in France in late 1960 in order to provide information on groundwater contamination. (Zwiorozek and Verba 58: 1994)

Vulnerability is a relative, non-dimensional, and unmeasurable property that depends on the characteristics of the aquifer, the geological and hydrological environment. (Antacus and Lambrex 290: 2007)

There are several ways to investigate and assess the potential for contamination in an aquifer: processing methods, overlapping recognition methods, and statistical methods. (Alma Serie 579: 2008)

In processing methods, simulation models are used to estimate the motion of pollutants. Statistical methods use correlation relationships between spatial variables and the amount of pollutants in groundwater. Index-overlapping methods combine the controlling parameters of the motion of pollutants from the ground surface to the saturation zone, and define an index called vulnerability in different parts of an area. (Dixon 329: 2005)

One of the most commonly used methods for aquifer vulnerability is the drastic method which has been provided by the US Environmental Protection Agency (US-EPA) to determine the potential for groundwater contamination (Aller et al., 83: 1987).

In this method, seven measurable factors or characteristics are estimated for the hydrologic system (Al Adamt et al., 307: 2003), (Babiker et al., 129: 2005). These factors include depth of water, nutrition grid, aquifer environment, soil type, topography, non-saturated area effect and hydraulic conductivity. These seven parameters appear in seven layers in the GIS software environment, where the analysis is done on them. In this model, a rating of 1 to 10 is assigned to the intervals of each of the hydrologic parameters based on their impact on vulnerability. Finally, after collecting and digitizing the hydrological information, seven newly-named factors, known as the drastic indexes, are obtained in accordance with (1-1):

$$D - \text{index} = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad (1-1)$$

In this equation, the DRASTIC letters are the hydrological parameters affecting the drastic model and the w and r indices are the rank and weight of each parameter, respectively, so the vulnerability index in this method is obtained by multiplying each parameter by its rank. (Rahman, 2008)

The advantages of this method can be the relative lack of data, ease of data acquisition, statistical accuracy, low cost, and use in vast areas. (Russen, 1994 and Allen et al., 1987)

In this research, drastic method has been used to evaluate the vulnerability of groundwater in Kuhdasht plain.

Data from nitrate values of groundwater in the plain has been used to verify the results obtained from the models. The stages of this research are as follows:

- Collecting information layers and data requirements
- Defining and explaining evaluation criteria, and digitizing the data and information
- Applying the weight obtained and storing the layers
- Defining appropriate methods for combining and integrating data
- Assessment
- Providing the output map (map of potential of vulnerability in Kuhdasht plain)

II. RESEARCH BACKGROUND

Research done in Iran

The dramatic method has been used in Iran as a case (Afrozi et al., 2012). The vulnerability of the Borujen-Fardanieh plain aquifer was studied using the drastic method. The zoning map obtained showed that about 66, 16 and 18 percent of the area had respectively a moderate, high and low vulnerability. Khosravi et al. (2012) in the Dehgolan plain of Kurdistan province investigated the vulnerability of aquifer using a drastic method and introduced 0.02% of the region as highly vulnerable. Amir Ahmadi et al. (2012) used the drastic model for the Davarzan Plain. The results of this study showed that the contamination and potential for contamination of aquifer are very high and the amount of nitrate consumption is very effective in aquifer contamination.

KheirkhahZarkesh et al. (2012), in a study entitled "The use of the AHP method to calculate the contamination potential of Eshtehard plain in GIS environment", evaluated the vulnerability of groundwater in Eshtehard plain. The results of the implementation of the drastic model in the study area indicate that the aquifer vulnerability index, which is obtained from the sum of the scores and weights of each parameter, is from a minimum of 74 to a maximum of 185. Moreover, the weight of each parameter was calculated using the AHP method, taking into account four parameters of hydraulic conductivity, depth to water table, rainfall and gradient, and a pairwise comparison of parameters. Accordingly, a new model was presented for assessing the vulnerability of the aquifer.

Research Done Abroad

Kabra and Zahuri (2008) assessed the vulnerability of groundwater for the Banyas catchment in the coastal areas using the GIS. The results of this study showed that 2, 54, and 39% of the study area are respectively within the range of low, moderate, and very high vulnerability. Kata et al. (2010) evaluated the inherent vulnerability of Githi aquifer in Cyprus using the drastic model and the GIS. The results of this study showed that the class of high vulnerability includes a vast region of the study area. Neuber et al. (2007) evaluated the vulnerability of groundwater using fuzzy logic and drastic method for Nepal. Comparison of fuzzy and drastic methods showed that the drastic method was more efficient and reliable, and 75% and 85% of the study area had moderate to high vulnerability, respectively. Stieger et al. (2006) studied the aquifer vulnerability in an area in the Portugal using the drastic model and reported that the amount of nitrate consumption is effective in the aquifer contamination. Shahid et al. (2007) used the drastic model for the vulnerability of the aquifer of western Bengal

to pesticides. Babiker et al. (2005) used the drastic model in the GIS environment to determine the areas prone to contamination due to human resources in Kakamigahara aquifer in the central Japan. They concluded that the western and eastern parts of Kakamigahara aquifer were identified as high and moderate vulnerable areas, respectively. The final map of Kakamigahara aquifer shows that there is a high risk of contamination in the eastern part of the aquifer resulting in high agricultural contamination potential. They also found that the pure supply parameter has the highest impact on the vulnerability of aquifer, and the soil environment, topography and hydraulic conductivity are in the next places.

Hasiniana et al. (2010) used the drastic model in the GIS environment to evaluate the vulnerability of groundwater of the northeastern aquifer in the Tamtsag basin in Mongolia; they concluded that only 2% of the study area has a moderate vulnerability to contamination and the remaining areas are in low-risk state. Zhou et al. (2010) used the DRAV model to evaluate the underground waters of the Tarim Basin in GenikHayan, in the northwestern part of China. In this model, D, R, A, AND V are groundwater depth, pure water supply, aquifer characteristics, and non-saturated environment lithology, respectively.

III. MATERIALS AND METHODS

Geographical location of the study area

Kuhdasht Range is one of the parts of Kuhdasht city located in Lorestan province, which is located at 47° 12 to 47° 52 E and 33° 17 to 31° 41 N. Kuhdasht study area has 2 main plains called Kuhdasht and Kashmahur, which are connected to the province center via the asphalt road of Kuhdasht - SarabDoreh - Khorramabad. The study area of Kuhdasht, with an area of 1129.3 square kilometers, is one of the study areas of the Karkhe catchment and is located in west of Lorestan province. This area is covered by Lorestan Regional Water Company. 301.5 square kilometers of its size include highlands. Kuhdasht and Kashmahur plains are 248.8 sq. Km and 52.7 sq. Km wide, respectively.

In general, the average altitude in plains and highlands is 1261.1 and 1396.2 m, respectively, and the total study area is 1360.1 m wide. Map (1-1) shows the position of the aquifer in the plain.

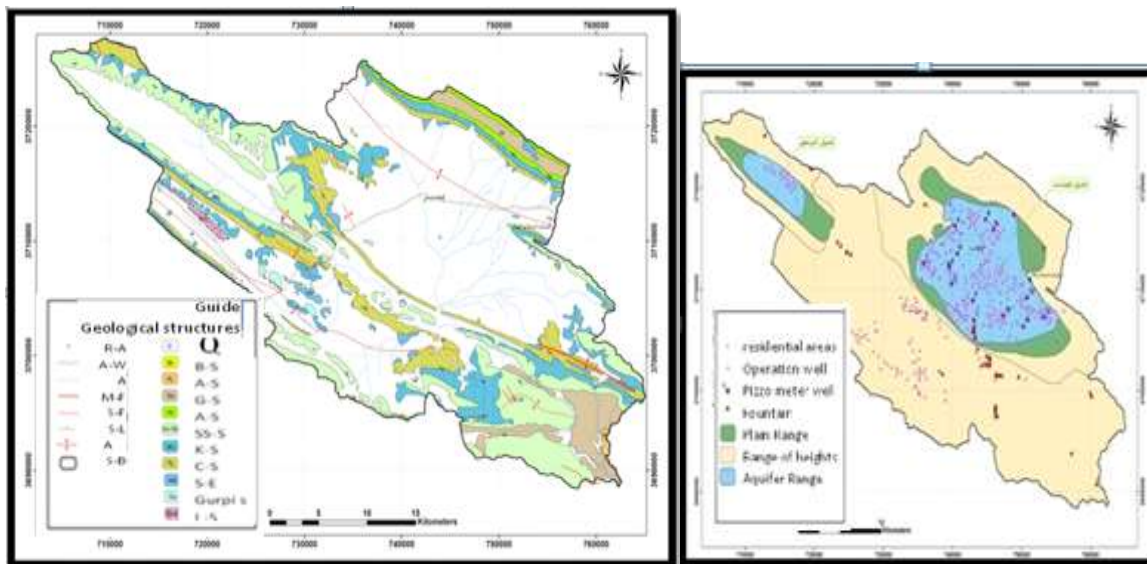


Fig (1-1). Geographical location of the studied area

General Climate Survey

Table (1-1). De Martonne coefficient values and climate type of Kuhdasht station (based on meteorological report and regional water company)

Average Annual Precipitation (mm)	Average temperature (centigrade)	De Martonne coefficient	Climate type
Semi-humid	27.27	16.5	450

Precipitation

The average annual precipitation of Kuhdasht plain was 459 mm in an indicator or long term period (water year from 1959-1960 to 2016-2017), while it was is 481.7 mm in 2016-2017; and according to the Meteorological Organization, the groundwater balance was 181 mm in 2013-2014. The maximum annual precipitation at Kuhdasht synoptic station in the long-term statistical period is 536 mm in 2001-2002 water year, and the minimum was 254.4 mm in 1999-2000.

Other long-term climatic parameters results in the study area are as follows:

Temperature: The daily average temperature value in a long-term period in Kuhdasht plain is 16.5 centigrade, while the maximum and minimum average values are 38.8 (August) and -0.1 (February) centigrade, respectively. The annual absolute minimum and maximum are -20.6 and 43 centigrade, respectively.

Relative humidity: The average relative humidity in a long-term period in the plain is equal to 50.1%, and the maximum and minimum values are 73% (January), and 29% (July), respectively.

Frosty days: The average number of frost days in a long-term period in Kuhdasht plain is 74.3 days.

Evaporation from free water level: The average annual evaporation from free water level in Kuhdasht plain is 1679.4 mm.

Evapotranspiration potential: The average annual evapotranspiration rate in Kuhdasht Plain is 1510 mm.

Evaporation from pan: The average amount of annual evaporation from the pan is obtained using gradient relationships and, accordingly, the amount of evaporation from the evaporation pan in Kuhdasht plain is 2375.6 mm.

Geology

In terms of stratigraphy, the geology of the study area has distension from the old to new within Kuhdasht-Kashmahur study area. The study area is located in the Zagros folded belt and follows its general trend (northwest - south east). The Zagros mountain range is a eugeosyncline with more than 12 kilometers of precipitation from Infracambrian to the present time which has begun stratigraphy through the Alpine orogenic movements. Zagros orogeny is one of the most important tectonic movements in the southwest of Iran, which started from the late Cretaceous and continues to this day. Kuhdasht plain is located in the tectonic zone of the simple stratified Zagros. And the anticlines and synclines with a prevailing direction of northwest-southeast depict its structures. The faults in the region are mainly due to the thrust faults and shortenings available in Zagros. These faults have mostly northwest-southeast and north-south directions.

In the studied area, formations of the second to fourth era have exposures; from the old to the new ones, they include: Imam Hasan section, Formations of Gurpi, Amiran, Talezang, Kashkan, Asmari-Shahbazan, Asmari, Gachsaran, Aghajari, Bakhtiari and Abroft. Alluvium of the fourth era which include sand, clay, silt and gravel, also cover the plain surface. Figure 1-2 also shows the geological status of the area.

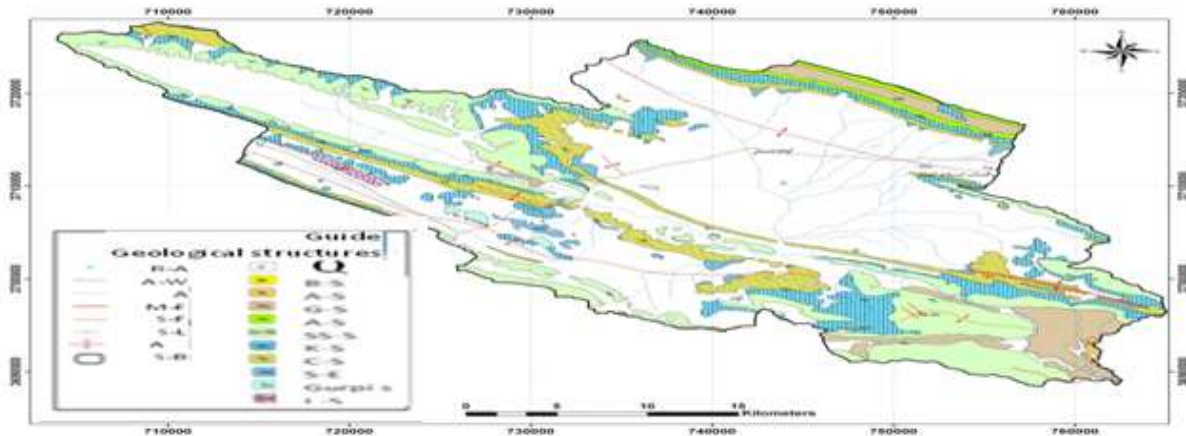


Fig 1-2. geological status of the area

Groundwater Unit Hydrograph

In order to provide the groundwater unit hydrograph of the study area, it was tried to use the correct data despite the lack of statistics and existence of deficiencies, the non-continuity of the monthly figures of the water level, the alignment of the sign points, and then the instability of the observational wells network (piezometric network displacement) toward the time. Therefore, at first, after eliminating the existing defects and problems, the statistics of the cultivars for the months without statistics were carried out through the process of fluctuation in the adjacent wells, then using the maps of the groundwater average level and the Thiessen network, the groundwater unit hydrograph of the plains has been provided.

Kuhdasht Plain

The groundwater unit hydrograph of Kuhdasht plain has been provided for the period from October 2007 to August 2009 for the range of balance and Thiessen network with an area of 136.30 square kilometers. Figure 1-3

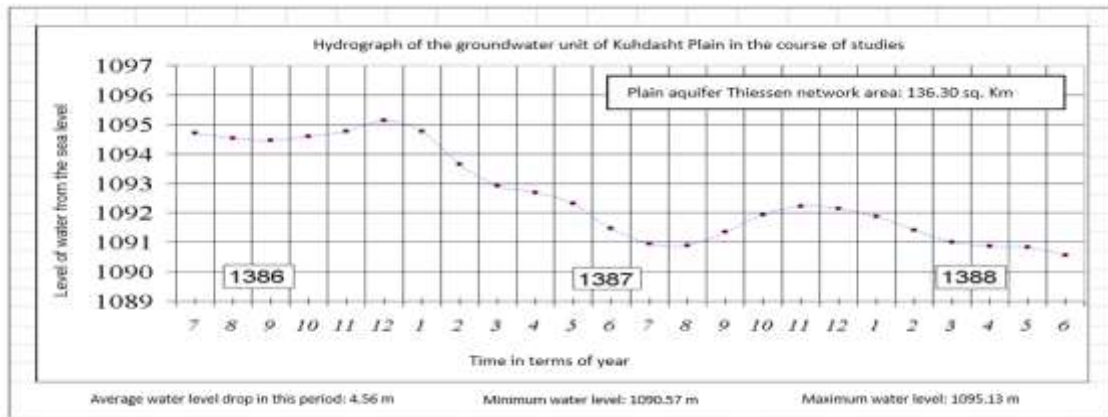


Figure 1-3. Groundwater unit hydrograph of Kuhdasht plain aquifer in the course of studies

Based on the unit hydrograph above, it is noted that the loss of the Kuhdasht aquifer during the aforementioned period was 4.25 m while it was 2.98 m in the balance year (March 2008 to March 2009).

Water Resources

River

The permanent river of Madian is located in the study area of Kuhdasht and rainfall runoff in the basin along with the outlet water from the springs and drainage of the plain and highlands provide water outlet from the river. Figure (1-4) shows the position of the hydrometric stations compared to the area and each other.

In this study, for estimation of runoff volume and total annual yield of the river outlet from the area, the data of Madian Rood-Baraftab hydrometric stations, which located near the outlet of the range and are representatives of surface water outlet from the range, were used. Regarding the correlation between this station and the Tang-Siab hydrometric station with the relation $Y = 1.662X - 0.83$, it was tried to restore the years without statistics. Based on 30 years of statistics from the water year of 1985-1986 to 2015-2016, the highest and lowest annual average values are related to 1994-1995 and 2015-2016 with 3.11 and 0.46 cubic meters per second, respectively, and the average annual yield during the statistical period is equal to 1.54 cubic meters per second. During the whole period of the statistical period, the lowest and highest monthly recorded figures belong to October 2015 and December is 1994. In total, the months with the minimum discharge at this station are: June, July, August, September, and October.

Since Madian Rood is a permanent river and a significant part of its discharge comes from the discharge of springs and drainage from underground water, in order to use the statistics and information of this station for calculating the balance, at first, we must separate the base discharge from the runoff. For this purpose, using daily discharge (if any) and also discharge in dry months of the year, according to the usual methods, we took steps for separation of base discharge and runoff resulted from direct precipitation.

Thus, in the Baraftab hydrometric station, the average amount of river discharge, the runoff rate, and base discharge were estimated to be 1.54, 0.83, and 0.71 cubic meters per second, respectively. Considering the rainfall in the upstream basin of this hydrometric station, the percentage of runoff from the total annual precipitation is estimated to be 6.5%. The amount of runoff generated from rainfall in the study area has been estimated according to the runoff coefficient obtained from the hydrodynamic station of Madian Rood-Baraftab and other hydrometric stations around the area and applying expert opinions. It is obvious that the percentage of runoff in the plains and altitudes is different and due to the fact that there is no hydrometric station on the plain and altitude border to determine the amount of runoff of highlands, these figures are estimated according to topography and geological maps, and other effective parameters, and finally, the equations of the balance, and they are listed in the relevant tables.

Table 1-2. Specifications of hydrometric stations

Station No.	Main river	Station name	Geographical attributes			Year of establishment	Basin area (sq.km)	Equipment			Considerations	
			Length	Width	Altitude			Eshel	Limnograph	Teleferic		
1	221321001	Dare Dozdan	Tang-Siab	47-12	33-23	880	1970	575	+	+	+	
2	220621001	Kashikan	Pol Dokhtar	47-43	23-10	650	1995	9270	+	+	+	
3	220622003	Kashikan	Afrineh	47-53	23-19	800	1995	797	+	+	+	
4	221322003	Madian Rood	Baraftab	47-48	23-19	790	1970	1139	+		+	
5	220921003	Kashikan	Doab Visian	47-53	33-35	950	1999	3745	+	+	+	
6	220622004	Kashikan	Afrineh	47-54	23-20	820	1970	6827	+		+	

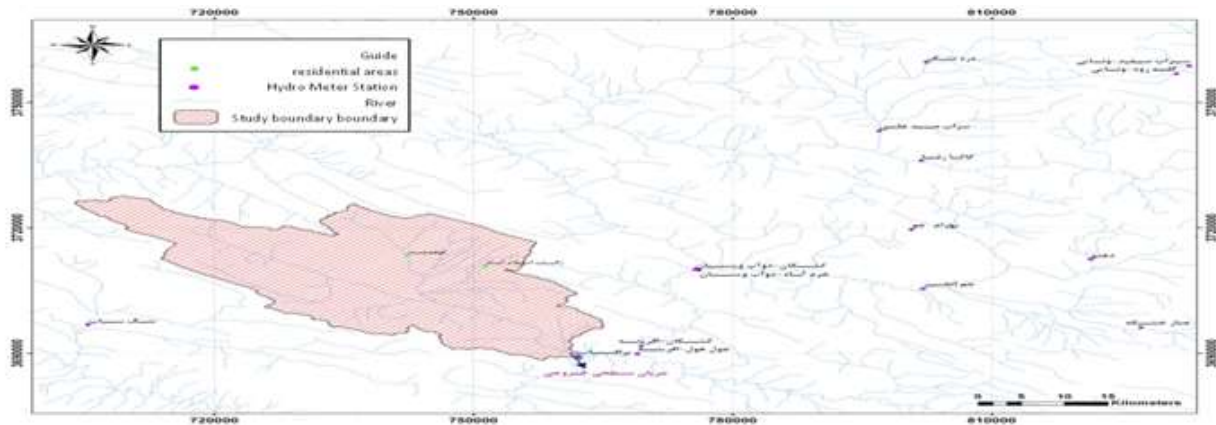


Fig1-4. Location of hydrometric stations in the study area and adjoining areas

Water table average

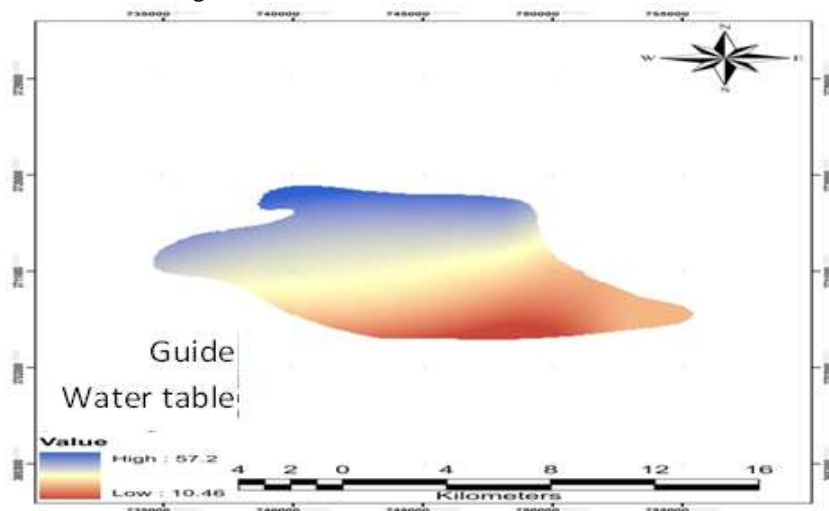


Fig 1-5. Water table average

Research Methodology

The vulnerability process in the GIS environment involves several operations. The first step is to select and prepare the desired criteria and constraints as map layers and then process them in the GIS environment.

In this research, the combination of GIS and multi-criteria decision making (MCDM) has been used for zoning. The combination of GIS and MCDM is a powerful tool that is very suitable for zoning, because GIS controls the data as an efficient tool, and MCDM is also used for appropriate and consistent rating to determine the potential of appropriateness of locations, according to the variety of parameters.

Selecting Required Maps and Software

A) Materials

The materials and data required to do this research are as follows:

- Topographic maps to provide DEM (Digital Elevation Model) and mapping of slopes
- Geological maps
- Data on groundwater resources
- Data on area rain gauge stations

B) Software used

The Arc GIS software was used to create and complete databases, digitize and edit maps, geo-reference the data, determine the coordinate system and image system, and align the weighted layers.

Necessity of project implementation with the help of GIS

Since the zoning process is an AMDM that can be implemented under the raster model, the suitable software for this process is the one that is active under the raster model and has the capability to use AMDM rules. In this

regard, the GIS has a wide range of capabilities in AMDM and also the raster base, which was chosen as the main software of the operation. The ability of GIS to store information that has spatial dependency, analyzing it, performing needed computations and displaying them in the form of detailed maps, charts and diagrams in a short amount of time, has put this new computer technology in a special place. This makes the use of GIS, as a means of collecting, processing, and analyzing spatial data, into the realms of all sciences that have some kind of geographic dependency. Information from different studies can be studied simultaneously by the use of GIS. The information for each field is made as a map layer. These layers are combined on each other and analyzed. Due to the features of the GIS, its use can both save time and increase computational accuracy, and ultimately, the resulting result will be highly accurate.

Parameters Evaluation

The vulnerability parameters in this study include groundwater depth, pure supply, aquifer environment, soil environment, topography, effect of non-saturated zone and hydraulic conductivity.

Fig 1-6. Drastic parameters

Scoring Information Layers

Scoring information layers is one of the most important steps in combining the information layers, determining the relative importance of the parameters used and assigning appropriate weight to each one. There are several methods for weighting information layers in studies that are referred to in the second chapter.

Drastic Method

Drastic factors

Drastic factors are a set of measurable parameters, access to information of which can be through variety of sources without any precise examination. A common ranking system has been designed to use the drastic factors. This system consists of three parts of weights, intervals and scores.

Weights

Each of the factors in the drastic model has been evaluated according to its importance compared to other factors. For each of the drastic factors, a relative weight of 1 to 5 is assigned, as in Table 1-3; the most and least important weight factors have the values of 5 and 1, respectively.

Table 1-3. Weights assigned to the parameters of the drastic model (Aller et al. 1987)

Specification	Weight
Depth to water table	5
Pure supply	4
Aquifer environment	3
Soil environment	2
Topography	1
Non-saturated environment	5
Hydraulic conductivity of aquifer	3

Intervals

Each of the drastic factors has been divided into important intervals or environments affecting the potential of contamination. According to Table 1-4, these intervals or environments have been classified.

Table 1-4. Ranking and weighting of drastic parameters (Aller et al., 1987)

Interval	Rate	Interval	Rate
Depth to water table (m)	W=5	Soil environment	W=2
0-1.5	10	Gravel or soil thin layer	10
1.5-4.6	9	Sand	9
4.6-9.1	7	Peat	8
9.1-15.2	5	Dense clay	7
15.2-22.9	3	Sandy loam	6
22.9-30.5	2	Loam	5
>30.5	1	Silty loam	4

Clay loam	3		
Pure supply (mm/year)	W=4	Fertilizer	2
<51	1	Non-dense clay	1
51-102	3		
102-178	5	Hydraulic conductivity (m/day)	W=3
178-254	8	<4.1	1
		¼-12.2	2
Aquifer environment	W=3	12.2-28	4
Silt and clay	2		
Silt and clay with a little sand and gravel	4	Unsaturated medium	W=5
Sand with some silt and clay	6	Karsi aquifer	9
Sand and gravel	8	Sand	8
		Silty sand	7
Topography (%)	W=1	Clay sand	6
0-2	10	Sandy silt	5
2-6	9	Sandy clay	4
6-12	5	Silty clay	3
12-18	3	Marl and clay	2
<18	1	Dense clay	1

Scores

Each of the intervals of the various drastic factors has been evaluated with respect to other intervals, which determines the relative importance of each interval according to the contamination potential.

The interval of each of the drastic factors is assigned by a score of 1 to 10 (Table 1-4). The result of the DRASTIC model is a numerical index that derives from the scores and weights assigned to the model parameters.

The DRASTIC index is as follows:

$$\text{DRASTIC Index} = D_R D_R + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W \tag{1-1}$$

Where R is the score and W is the weight.

It's worth noting that since the scores can range from 1 to 10 and the total drastic weights is 23, the minimum and maximum of this index are 23 and 230, respectively. This means that the areas with vulnerability index 23 and 230 have the lowest and highest risks of contamination, respectively.

Drastic model assumptions

There are 4 main assumptions in the dramatic model:

- The contaminant arrives at the aquifer from the water table.
- Penetrated rainwater is the source of contaminants transfer to groundwater.
- The ability to leave contaminants is equal to the mobility of water.
- The environment evaluated using a drastic model is at least 40 acres.

The Overlapping Model and the Combination of Information Layers

Index Overlapping Model or Simple Additive Weighting (SAW)

Simple Additive Weighting is one of the most commonly used techniques in local multi-criteria decision making. This method is also called weighted linear combination or scoring method. This method is based on the concept of weighted average.

The decision maker or the analyst directly assigns some weights to the criteria according to the relative importance of each criterion examined. Then, by multiplying the relative weight by the value of that attribute, it obtains a final value for each option (e.g. the element of the image in spatial analysis). Once the final value of each option has been determined, the options that have the highest value will be the most appropriate option for the target (Shahabi et al., 2008). The target can be to determine the suitability of the land for a particular application or to assess the potential of a particular occurrence.

In this method of decision making, the value of each option Ai is calculated by (1-2).

$$A_i = \sum_{j=1}^n w_j \times x_{ij} , \sum w_j = 1 \tag{1-2}$$

In this equation, wj is the weight of the index j, and xij is the value of the i-th place. In other words, this value can indicate the degree of suitability of the i-th place in this relation with the j-th index. n is the total number of indices, and Ai is the value that ultimately gets to i-th place.

As shown in Fig. 1-7, the role of the weighing of the layers in this method is well evident and there is also the possibility of ranking options in this method.

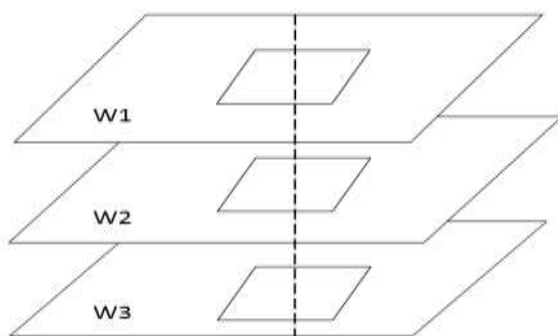


Fig 1-7. Simple weighted sum (adapted from: Goodarzi, 2012)

Error Sources

Six classes of error sources have been shown in Table 1-5 illustrating the various stages discussed in the development of a vulnerability assessment. The first three classes are related to data errors and the second three classes are related to the model errors. Since each step needs interpretation to evaluate the vulnerability, the interpretation is also shown as an error source in each class.

Table 1-5. Error sources for assessing groundwater vulnerability (Adopted from: Akhtari, 2006)

1	Error in obtaining data A) Careful location determination
	B) Sample collection and evaluation
	C) Analysis and laboratory measures
	D) Interpretation
2	Errors due to time and place variability A) Incidental sampling errors B) Skewed C) Relative area, interpolation, extrapolation
	D) Effects of scale, variations in variance in the result of averaging
	E) Interpretation
3	Error in digitizing and storing data
	A) Inserting data B) Age of data C) Changes in the form of storage D) Errors in data access plans
	E) Application of substitute data and trends
	F) Scale settings G) Determination of the boundaries H) Changes in the presentation of data I) Interpretation
4	A) Numerical, shear and rounding errors
	B) Discrepancy errors C) Difficulty in problem solution convergence D) Interpretation

5	Modeling and conceptual errors
	A) Presentation and pairing errors B) Parameter identification C) Scale effects D) Interpretation
6	Output errors
	A) Determination of the boundaries B) Classification to vulnerable groups C) Interpretation

Model Verification

To validate the results obtained from the drastic model, we used the nitrate values of the wells in the study area. Since the fertilizers used in the study area are often animal or nitrate fertilizers, the nitrate ions in underground damage were analyzed.

Chapter : Results and Discussion

1.1 Introduction

After identifying the effective criteria for assessing the vulnerability of the aquifer, this chapter outlines the necessary operations for zoning Kuhdasht aquifer in the GIS environment and, at the end, identifies the potential for contamination.

1.2 Preparation of the drastic model layers

1.2.1 Layer of depth to water table

The depth of water is defined as the distance from the ground surface to the groundwater table (Al Kuisi et al., 2006). Therefore, water depth is an important parameter, which determines the thickness of the materials that the pollutant passes through before reaching the aquifer (Xiaohu wen, 2009). Increasing this thickness leads to the purification and removal of contamination by the soil unsaturated zone (Azad Shahraki et al., 2010). In order to provide this layer, data collected from depth to water table of piezometers of Kuhdasht plain were used. Then, this layer was prepared by interpolating the points from the mean depth to water table of piezometers by the spline method. Then, according to the criteria of the drastic model, the depth layer to the water table was classified and valued into the ranges defined by the drastic method. Figure 1-8 shows the zoning of the studied area based on the water depth parameter.

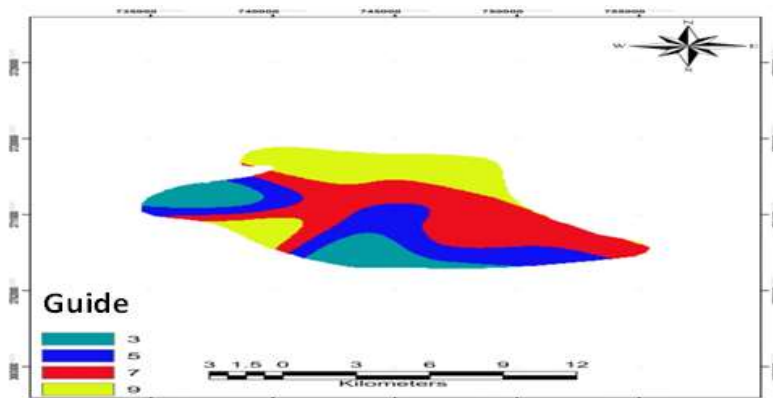


Fig 1-8. Water Depth Map

This layer is placed in 4 classes of 3, 5, 7, and 9. Class 7 with 35.74% of the total area has the largest area. Classes 9, 5, and 3 consist 26.66%, 22.97%, and 14.63% of the total area, respectively.

1.2.2 Pure supply layer

Pure supply shows the amount of water per unit of ground surface that penetrates the surface of the ground and supplies the water table (Ranjan, 2006). Generally, increasing the level of supply increases the potential for groundwater contamination (Karami, 2007). Pisco method was used to prepare the pure supply map. In this method, slope, rainfall, and permeability of the area soil are used to obtain the potential of supply in the region.

To calculate the pure supply map, the maps of slope, rainfall, and permeability of Kuhdasht plain were provided first, and then, they were classified according to the criteria in Table 1.6. Then, the aforementioned maps were overlapped using ArcGIS software, and finally the pure supply layer was obtained (Figure 1.9). Pisco equation for the calculation of supply potential in a region is as follows: (Karami, 2007)

$$\text{Amount of supply} = \text{Percentage of slope} + \text{Rainfall} + \text{Soil permeability}$$

Table 1.6. Supply scores for the studied area (Karami, 2007)

a) Slope		b) Rainfall		c) Soil permeability		Amount of supply	
Slope %	Factor	Rainfall (mm)	Factor	Range	Factor	Range	Factor
<2	4	>850	4	High	5	11-13	10
2-10	3	700-850	3	Moderate to high	4	9-11	8
10-33	2	500-700	2	Moderate	3	7-9	5
>33	1	<500	1	Low	2	5-7	3
				Very low	1	3-5	1

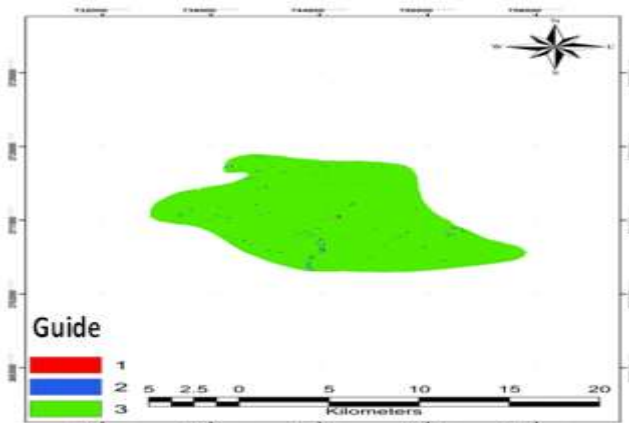


Figure 1.9. Pure supply map

According to figure 1.9, the supply rate is divided into three classes of 1, 2, and 3. Class 3 with 99.20% of the total area has the largest area. Classes 2 and 1 consist 0.751% and 0.461% of the total area, respectively.

1.2.3 Aquifer environment layer

Consolidated and non-consolidated geological materials may form the body of an aquifer. Generally, more coarse-grained materials lead to more fractures and seams and gaps, more permeability and lower drain capacity in the aquifer (Yang & Wang, 2010). In order to prepare the layer for this parameter, the log of operation wells in Kuhdasht plain were used. According to the logs of operation wells and the criteria of the drastic model, each of the wells has been ranked. Then, using one of ArcGIS software extensions, the Thiessen network of the area was constructed based on the position of the piezometers toward the boundary of the study area. Finally, the resulting layer was converted to the Raster layer based on the rank given to each well. Figure 1-10 shows the zoning of the studied area based on the aquifer environment parameter.

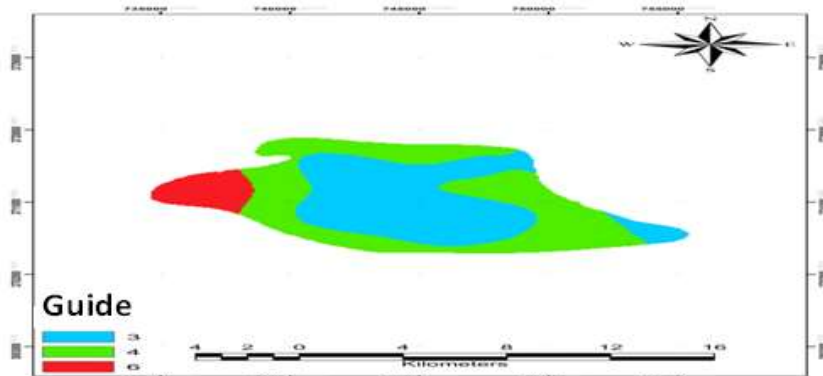


Fig 1.10. Aquifer environment map

As shown in Fig. 1.10, the aquifer environment layer is divided into 3 classes of 3, 4, and 6. Class 4 with 46.01% of the total area has the largest area. Classes 3 and 6 consist 45.86% and 8.11% of the total area, respectively.

1.2.4 Soil environment layer

The environment of the upper and weathered parts of the soil is the unsaturated area. Soil properties affect the rate of supply penetration into the aquifer, pollutant emissions, and pollutants purifying process (Al Hallaq & Abu Elaish, 2011). In order to prepare the soil environment, after identification of different types of soil in the area, the soil layer was extracted and stored as a Raster layer. It was then classified and valued according to the criteria defined by the drastic model. Figure 1-11 shows the zoning of the studied area based on the soil environment parameter.

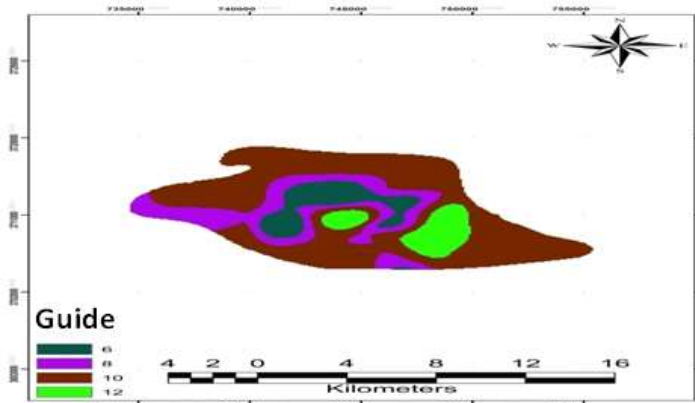


Fig 1-11. Soil environment map

As shown in Fig. 1.11, the soil layer is divided into 4 classes of 6, 8, 10, and 12. Class 10 with 32.96% of the total area has the largest area. Classes 12, 6, and 8 consist 29.74%, 25.12%, and 12.18% of the total area, respectively.

1.2.5 Topography layer

The topography refers to the ground slope and is expressed as a percentage of slope. Low-slope areas tend to keep water longer. This allows the potential for further penetration of supply water and the potential for greater contamination (Ckkraborty et al., 2007). In order to provide this layer, Digital Elevation Model (DEM) of the region was prepared. Then, the slope map was extracted from this digital model. Finally, to provide the topography layer, the obtained slope map was classified and evaluated using the criteria of the drastic model. Figure 1.12 shows the zoning of the studied area based on the slope parameter.

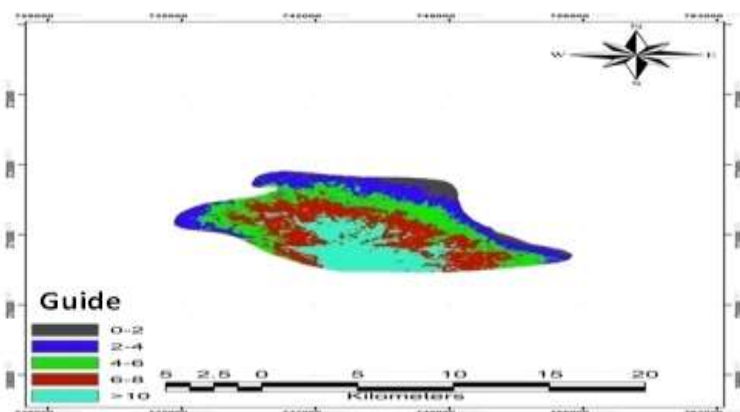


Fig 1.12. Slope map

As shown in the Figure, the area slope is divided into 5 classes of 1, 3, 5, 9, and 10. Class 9 with 29.63% of the total area has the largest area. Classes 5, 10, 3, and 1 consist 24.8%, 21.53%, 18.49, and 5.52% of the total area, respectively.

1.2.6 Effect of the unsaturated area

The unsaturated area refers to the upper surface of the water table, which is unsaturated or discontinuously saturated, and is located between the soil layer and the water table. If the unsaturated area has a high permeability, it will be assigned a high vulnerability rank. (Al Hallaq & Abu Elaiash, 2011). To provide this layer, logs of wells and piezometers in the plain were given. Then, according to the logs of the wells, a rank was assigned to each of the wells based on the criteria of the drastic model. Then, as in the aquifer environment, the Thiessen network of the area was constructed based on the position of the piezometers toward the boundary of the study area. Finally, the resulting layer was converted to the Raster layer based on the rank given to each well. Figure 1-13 shows the zoning of the studied area based on the unsaturated area parameter.

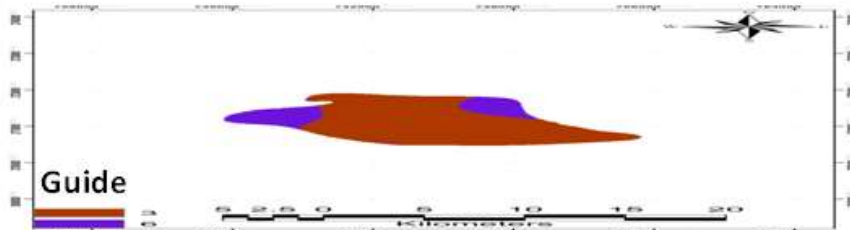


Fig 1.13. Unsaturated environment map

As shown in the Figure, the unsaturated environment layer is divided into 2 classes of 3 and 6. Class 3 with 77.54% of the total area has the largest area while class 6 consists 22.46% of the total area.

1.2.7 Hydraulic conductivity layer

The ability of aquifers in the transport of water is called hydraulic conductivity, which controls the groundwater flow rate under a certain hydraulic slope (Karami, 2007). To provide this layer, data from the pumping tests of wells in the area were used to calculate the transmission coefficient and while the plain hydraulic conductivity map was obtained by dividing the transmission coefficient by the aquifer thickness map. Finally, the hydraulic conductivity map was classified according to the hydraulic conductivity parameter in the calculation of the drastic index.

Figure 1.14 shows the zoning of the studied area based on the hydraulic conductivity parameter.

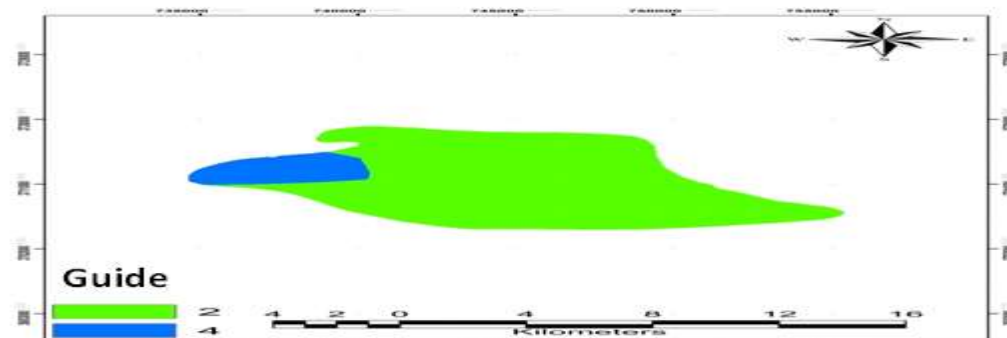


Fig 1.14. Hydraulic conductivity map

As shown in the Figure, the hydraulic conductivity layer is divided into 2 classes of 2 and 4. Class 4 with 89.97% of the total area has the largest area while class 2 consists 10.03% of the total area.

1.2.8 Drastic Vulnerability Index

Equation (1-1) was used to obtain the final drastic index. In order to better understand the vulnerability, we have to choose a method to display the vulnerability of the aquifer better and to compare the different areas simultaneously. Aller et al. (1978) method was used to display the vulnerability maps better. A color scale is used in this method, so that the vulnerability index is firstly divided into intervals by considering the conventional boundaries. Then these colors are allocated from blue to red. The blue shows a low vulnerability, green the moderate vulnerability, and red the high vulnerability.

Since the minimum and maximum possible drastic index using these parameters are 23 and 230, respectively, this interval is divided into eight classes as follows:

Less than 79 (no risk of contamination)

80-99 (very low vulnerability)

100-119 (low vulnerability)
 120-139 (moderate vulnerability)
 140-159 (moderate to high vulnerability)
 160-179 (high vulnerability)
 180-199 (very high vulnerability)
 More than 200 (completely vulnerable)

The results of the drastic index in the study are between 110 and 168. According to the classification above, this interval is classified as follows:

- 100-119 that falls within the low vulnerability range.
- 120-139 that falls within the low to moderate vulnerability range.
- 140-159 that falls within the moderate vulnerability range.
- 160-179 that falls within the high vulnerability range.

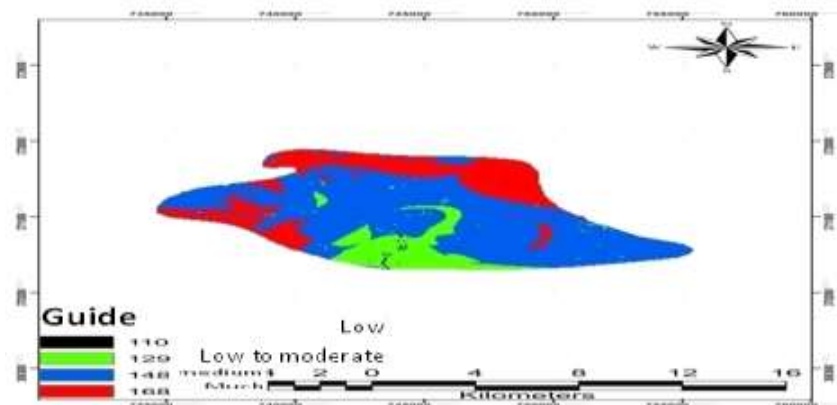


Fig 1.15. Vulnerability map

1.2.9 Verification of the drastic model according to the concentration of nitrate

One of the disadvantages of the drastic method is that the classification and valuation of the parameters are somewhat professional and dependent on the condition of the aquifer, which in turn results in uncertainty in the results (Ruhafzarian 1999: 96). Therefore, it is necessary to calibrate the drastic model using the dispersion of the concentration of natural contaminants such as nitrates, pesticides, etc., which result in a specific aquifer vulnerability. Due to the fact that in the studied area, agriculture has a certain boom and chemical and animal fertilizers are often used, nitrate ion is used for model verification, so it is expected that the concentration of nitrate in groundwater is high due to the deposition of these fertilizers from the surface of the soil and their transfer to the aquifer. In addition, due to the mobility of nitrate and the long-term survival time of nitrate in groundwater, and since nitrate is one of the important indexes for the quality of drinking and agriculture water, in this study, nitrate concentration data of 14 wells were used to calibrate the drastic model. Figure 1.16 shows the nitrate contamination zoning map in Kuhdasht plain aquifer.

Adjusting nitrate concentration on the vulnerability map, it was found that all points with high nitrate are in an area with high contamination force that can confirm the accuracy of the model.

As can be seen in Fig. 1.16, the highest concentration of nitrate contamination is in the range of northwest, northeast, center, south and southwest of the plain. Also, contamination in the southern and southeastern parts of the region is more intense and overlaps with regions with high vulnerability potential in Figure 1.16.

In general, it can be concluded that there is a very close relationship between the extent, the plain and the intensity of distribution of nitrate concentration in the aquifer and the potential of the plain vulnerability.

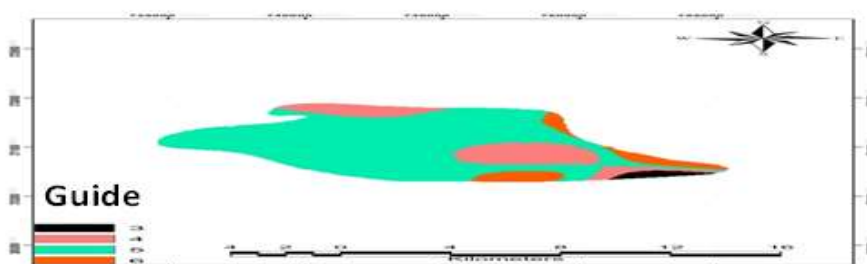


Fig 1.16. Nitrate map

Chapter 2: Conclusions and Suggestions

2.1 Introduction

In this research, the intrinsic vulnerability zoning of Kuhdasht plain aquifer against contamination was prepared using the drastic model in GIS environment. Due to the fact that Kuhdasht plain is one of the important plains of Lorestan province, this plain was selected for study.

2.2 Conclusion

In this research, the inherent vulnerability zoning of Kuhdasht plain aquifer against contamination was prepared using the drastic model in GIS environment. Due to the fact that Kuhdasht plain is one of the important plains of Lorestan province, this plain was selected for study. The potential vulnerability map shows the inherent vulnerability of the aquifer and can only be used as a primary tool for future development. In addition, this tool does not replace some of the specific studies in the site and does not provide any information on the type of contaminant and its amount.

- The zoning of the vulnerability of Kuhdasht plain aquifer, which is obtained from the combination of seven raster maps of the drastic model parameters, considering the weight of each parameter in the GIS environment, indicates that in the area of Kuhdasht Plain, parameters of water depth and unsaturated environment have the most effect on determining the vulnerability of aquifer while the slope parameter has the least effect. Nitrate ions were used maps (as natural contaminants in the area) for verification of the vulnerability maps. Matching the nitrate ion on the final drastic map, it was determined that all points with high nitrate are in the high contamination range, approving the accuracy of the model. According to the zoning map obtained, about 0.98%, 12.98%, 62.56%, and 23.48% of the study area were within the low, moderate, moderate to high, and high vulnerability ranges, respectively. Due to the complexity and cost of eliminating contamination from groundwater resources, aquifer vulnerability zoning can be provided as a valuable tool to authorities in order to make decisions for managing aquifer. These decisions could include applying management of agricultural fertilizers and urban sewage to more secure areas. Therefore, the control of this area against contamination should be considered. The nitrate contamination in this area is high, so this area needs more care as well as certain restrictions.
- In the studied plain, the maximum depth of contact with water is 57.2 meters and the minimum level of contact with water is 10.46 meters.
- The depth of the groundwater in the plain shows that the depth of contact with water increases from the south to the north.
- Pure supply layer, which is a combination of three layers of topography, penetration, and rainfall, shows that the southwestern and central regions have a lower pure supply value than other areas.
- The aquifer environment layer shows that most of the plain areas have sandy sediments along with some fine-grained sediment such as silt or clay, which increase the risk of vulnerability.
- The soil layer of the plain studied includes 4 classes. The high levels of these classes indicate that the permeability level in the area is high and this increases the potential for aquifer vulnerability.
- The topographic layer, which actually represents the slope, shows slight variations. The major part of the area contains a slope of less than 2%, which increases the drastic index and consequently the potential for aquifer vulnerability.
- The non-saturated environment layer is divided into 4 classes. Approximately, the major part of the region has fine-grained sediments such as clay, silt and the rest of the area have coarse-grained sediments such as sand.
- The hydraulic conductivity layer shows that the majority of the study area has a hydraulic conductivity of 12.8-28 m/day, which is characterized by a score of 4.
- The results of the drastic index in this study for Kuhdasht plain is between 110 and 168.
- According to the results obtained, about 0.98%, 12.98%, 62.56%, and 23.48% of the study area were within the low, moderate, moderate to high, and high vulnerability ranges, respectively.

Suggestions

- Given that the drastic model is an estimator model, it is suggested to conduct vulnerability assessment using methods such as fuzzy logic and neural network, and compare their results with the drastic model and actual data, in order to achieve more reliable results from vulnerability assessment and to identify the best way for evaluation of vulnerabilities.
- Since the information layers are necessary to launch and run any geographic information system (GIS), it is recommended to provide a complete and accurate database of these areas and make them available to users.

- According to the results obtained, it is suggested to less exploit the areas that are more prone to contamination and vulnerability.
- Since the major part of the study area is agricultural land, it is recommended to avoid chemical fertilizers whose composition is mostly nitrates.
- The removal of contamination from groundwater resources is costly, so this zoning can be provided as a valuable tool for the authorities to help them make the necessary decisions for land use and aquifer management. These decisions could include applying management of urban development, and the use of agricultural fertilizers and urban sewage to more secure areas and land use change.

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