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SENSITIVITY ANALYSIS AND VULNERABILITY MAPPING OF THE GUILAN AQUIFER USING DRASTIC METHOD

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ABSTRACT

Vulnerability of the water resources is a continuation of such trends. The first step in management of the groundwater resources is a determination of the vulnerable areas. The objective of this research was determining the vulnerability assessment of the central plain of Gilan using DRASTIC model. Principles of the model are based on overlaying of seven thematic maps of depth to water table, net recharges, aquifer media, soil media, topography, vados zone and hydraulic conductivity by considering appropriate weights and rates. The database was constructed by introducing the mentioned maps. Index of DRASTIC model for aquifer vulnerability of the central plain Gilan was ranged in 82-182. In this plain, there was not very much and very low vulnerability classes. The final map of DRASTIC model showed that %¬48.64 of the area has high vulnerability and %¬50.55 has medium vulnerability and only a small area of plain (%0.81) has low vulnerability. The statistical summary of the DRASTIC model elements shows that the element of depth to groundwater table has the greatest impact on DRASTIC model. Also based on the map remove and single element sensitivity, depth to groundwater table is identified as the effective element in the central plain of Gilan. The results of the correlation between the elements of DRASTIC model and nitrate concentrations showed that there is the highest correlation between nitrate and depth to groundwater table. The average concentration of nitrates is 8.92 mg/lit in the wells studied at the Central Plains Gilan. In all wells studied, nitrate concentration was lower than the recommended level by US Environmental Protection Agency (45 mg/lit).

Contribution/Originality: This study is one of very few studies which have investigated via DRASTIC index for sensitivity analysis of effective parameters which was validated by using of two methods for the map remove and single element in amount of nitrate pollution.

1. INTRODUCTION

Indiscriminate and uncontrolled discharge of municipal sewage and industrial wastewater, agricultural drainages with chemical fertilizers and pesticides, and overexploitation of fresh water throughout the world are among the main reasons for the decline in water quality and quantity. Water pollution has the highest impact on human health. Hence, we must move in the direction in which the sustainable and efficient management could be achieved while protecting current sources from further destruction. Because of reduction or contamination of conventional surface waters in recent decades, the attentions have focused on groundwater resources and thereby, most of such resources have been declined in terms of quality and quantity. The groundwater is considered as a significant water resource due to less pollution-susceptibility and higher storage capacity than surface water [1]. The significant point and non-point sources of pollutants resulting from human activities above ground and penetration of pollutants into the aquifers reduce groundwater quality. Therefore, prevention of groundwater contamination is essential in management of these water resources [2]. One of the best strategies to prevent groundwater pollution is determination of the aquifer vulnerability and leading management efforts toward these areas in order to maintain water quality. Aquifer vulnerability is often defined as an intrinsic feature of the groundwater system. It may be expressed either by vertical transmission of contamination in the unsaturated zone or horizontal transfer in the saturated zone in an area [3]. In this paper, the vulnerability map of Gilan Plain was prepared in GIS environment with DRASTIC Model. Then, sensitivity analysis was carried out for the model. Finally, data obtained from the model were compared with collected data of nitrate.

1.1. Background of Study

The first semi-automatic project using the concept of DRASTIC and GIS technique was done by Van Stempvoot. at the University of Kansas in 1993 Van Stempvoot, et al. [4]. Panagopoulos, et al. [5] used DRASTIC Model for groundwater pollution risk assessment in Trifilia state on the Mediterranean coast. In this study, simple statistical methods and nitrate concentration in the groundwater was used for modifying DRASTIC Model. The correlation coefficient of the modified method was greater than the original method by 33% Panagopoulos, et al. [5]. Denny, et al. [6] suggested a modification in the DRASTIC Model by introducing the structural characteristics of crushed bedrock of aquifers in some areas of Canada. Bedrock geological map, soil map, geological information, wells' information, and topographical data were collected in an extensive GIS database based on the conventional principles of DRASTIC indices assessment Denny, et al. [6]. Boughriba, et al. [7] used DRASTIC Model in GIS software environment for assessment of the groundwater vulnerability in Anged Aquifer in Morocco. They prepared the DRASTIC modified map obtained from total DRASTIC indices and small monitoring network maps including two categories, high and medium. Then they integrated the map with land use map to obtain map the potential risk of contamination. They stated that the new prepared map includes three different categories, medium, high, and very high Boughriba, et al. [7]. Babiker, et al. [1] applied DRASTIC Model in GIS environment to determine susceptible points to pollution from human activities in Kakamigahara Aquifer in Japan. They concluded that the western part of studied aquifer falls in the high category, while, the eastern part of the aquifer falls in the medium category. The final aquifer vulnerability map shows that the high risk of contamination is in the eastern part of aquifer due to agriculture. They also realized that the component, net recharge has the greatest impact on the aquifer vulnerability, followed by the soil environment, topography, the vadose zone, and hydraulic conductivity [1].

The water problems in Iran with an average annual rainfall about one-third of the world annual rainfall [8] are critical and serious and reduction in these scarce resources has deteriorated this status. The northern region of Iran (Guilan and Mazandaran Provinces) is considered among most rainy regions in the country. However, increased temperature, decreased precipitation, and drought in recent years were very significant, so that, surface water could not meet the agricultural and potable needs. Thus, in recent year, the use of groundwater resources has been greater than in previous years. It makes the studies on the pathology and zoning the damages in groundwater undeniable. The aim of this study is to prepare vulnerability maps and to present proper management options for conservation of the Guilan Plain aquifer because of its special position as agricultural and tourism core. In this respect, it is necessary to modify the DRASTIC Model for local conditions of the region by providing an appropriate methodology in order to achieve more accurate results.

2. MATERIALS AND METHODS

2.1. Drastic Method

The word "DRASTIC" is an abbreviation of parameters controlling groundwater pollution in a hydrological system. It is an empirical and standard model for vulnerability assessment of groundwater using hydrological factors. This model was first prepared in America Soil Protection Agency to estimate the vulnerability of groundwater on a regional scale [9]. The ultimate goal is to estimate the vulnerability using 7 hydrological parameters and to prepare the vulnerability maps of different regions. This model is widely used in most countries, because the inputs used for applying this model are generally available or easy to prepare.

2.2. Drastic Method Parameters

Drastic is abbreviation for the following seven parameters:

2.2.1. Depth to Water Table (D)

Groundwater depth includes a thickness of the ground pollutants must travel before they reach to the groundwater table. This parameter has great significant because it is equal to unsaturated weight and there is an interaction between pollutants and subsurface materials. The higher is the depth, the more time is needed by pollutants to reach to the groundwater table. As a result, factors reducing pollution such as chemical decomposition, absorption, releasing, etc. have more opportunity to dilute and reduce the pollution.

2.2.2. Net Recharge (R)

Recharge is the amount of water that penetrates from the ground surface and reaches the groundwater table. Therefore, the recharge is an important parameter in terms of penetrating and transporting the pollutants to the saturated zone. Water recharge makes the pollutants transfer vertically, reach the water table, and move in the aquifer horizontally. The parameter also controls the water volume that causes releasing and dilution of pollutants in the saturated and unsaturated zones. Usually, the higher the recharge rate, the more potential of the groundwater contamination. Several factors affect the amount of recharge rate such as soil permeability, the amount of precipitation and the slope.

2.2.3. Aquifer Media (A)

Is a part of water table that all its porosity is water saturated, and have the ability to store and transport the water. The particle size and their hardening and cementation are among the very important factors because they affect the amount of pollutant transport into the table. However, the table material increases or decreases the amount of pollutant rate by affecting the hydraulic conductivity. The groundwater movement rate depends on the permeability of saturated zone components which in turn affected by the porosity, particle size, the hardening rate and the course maze. These factors determine the course length of groundwater flow, and are very important to set a time for processes which play a role in pollution reduction.

2.2.4. Soil Media (S)

Soil as the first layer exposed to the pollutants is important and has a significant effect on the recharge. Potential of soil contamination depends on characteristics such as texture, permeability, organic matter content and soil thickness. Soil texture is associated with sand, silt and clay particles. In the coarse sandy soils, water moves quickly. Therefore, it has less ability to absorb chemicals by own organic matter. High permeability of soil increases the leakage of pollutants into the table. Organic matter content affects soil's ability to retain and absorb the pollutants. Soil thickness also influences the pollution reduction. The higher is the soil thickness, the pollution reduction processes have greater opportunity to reduce pollutants in the soil. In general, it can be said that fine-grained soils with low permeability and high clay content cause little potential for groundwater pollution.

2.2.5. Topography (T)

The topography is referred to the ground surface slope. The slope affects the pollution flow and is related to the impact on the water flow and soil expansion in the region. Generally, the slopes between 0% and 2% have the greatest potential for contamination penetration and the slopes above 80% have the lowest potential.

2.2.6. Impact of Vadose Zone (I)

This layer of subsoil extends to the water table. As soil layer, the unsaturated layer affects the vulnerability potential and depends on the environment characteristics and permeability of its components. Most chemical and physical processes are strongly influenced by the depth. That is, the more is the depth the more time is provided to reduce pollution by these processes. Therefore, the potential reduces with depth. In addition, purification and distribution of pollutants significantly depend on the physical properties of the environment. This factor is measured less than other factors, because obtaining information about this factor is difficult and expensive. Exploratory drilling, observational boreholes and field and laboratory observations and measurements are appropriate to estimate the saturated zone. The estimation methods are often associated with a disturbance. Because these methods affect the natural flow of water, observations and measurements, and their properties.

2.2.7. Hydraulic Conductivity (C)

The hydraulic conductivity of a water table indicates the capacity of the groundwater mobility in the saturated environment. Therefore, the mobility potential of pollutants carried by groundwater is approximately equal to the hydraulic conductivity of table. Hydraulic conductivity depends on the pores, fractures, joints, and inter-granular porosity. This parameter controls contaminant movement and distribution from the point of infiltration to reach to the saturation zone. Hence, there is the higher pollution potential in places with the high hydraulic conductivity.

2.3. DRASTIC Vulnerability Index Formulation

The values between 1 and 10 have been attributed to each parameter based on their classification. Determination of DRASTIC indices for each area includes each rating in every parameter weight and the value obtained for each cell. This is achieved by summing up the values obtained for each parameter. Index shows high susceptibility of the groundwater and the low value indicates low susceptibility to pollution. The index was calculated using the following equation (1). Where, r is the rank and W is the weight of each parameter. Table 1 shows the range of aquifer vulnerability.

$$I_d=D_rD_w+A_rA_w+S_rS_w+T_rT_w+C_rC_w+R_rR_w+I_rI_w \qquad (1)$$

2.4. Weighting and Valuation of DRASTIC Parameters

Valuation and weighting method was used to determine vulnerability index by DRASTIC Method. In this model, three factors, weighting, ranges, and values were used to estimate the DRASTIC index. A weight ranges from 1 to 5 has been assigned to each parameter based on the degree of its importance in vulnerability estimation and in order to multiple the model. The parameters with the highest importance are weighted 5 and the parameters with the least importance are weighted 5. Table 2 shows effective parameters in DRASTIC Model and the weights of each parameter. Rating each of these parameters is based on their position in these ranges.

Table-1. The range of aquifer vulnerability

Vulnerability	Classification of vulnerabilities
Very low	< 46
low	47-92
moderate	93-136
high	137-184
Very high	185 <

Source: Environmental Protection Agency

Table-2. Effective parameters in the model and the weights of each parameter

Parameter	Range	Rating	Description	Relative weighting
Depth to water (D) (metr)	0-5	10	Refers to the depth to the water surface in an unconfined aquifer. Deeper water table levels imply lesser chance for contamination to occur. Depth to water is used to delineate the depth to the top of a confined aquifer.	5
	5-15	9		
	15-30	7		
	30-50	5		
	50-75	3		
	75-100	2		
	>100	1		
Net recharge (R) (mm)	0-2	1	Indicates the amount of water per unit area of land which penetrates the ground surface and reaches the water table. Recharge water is available to transport a contaminant vertically to the water table, horizontal with in an aquifer	4
	2-4	3		
	4-7	6		
	7-10	8		
	>10	9		
Aquifer media (A)	Massive shale	2	Refers to the consolidated or unconsolidated medium which serves as an aquifer. The larger the grain size and more fractures or openings with in an aquifer, leads to higher permeability and lower attenuation capacity, hence greater the pollution potential	3
	Metamorphic/igneous	3		
	Weathered met./igneous	4		
	Bedded sandstone, Limestone			
	Shale sequences	6		
	Massive sandstone	6		
	Massive limestone	6		
	Sand and gravel	8		
	Basalt	9		
	Karst limestone	10		
	Soil thin or absent	10		
Soil media(s)	gravel	10	Refers to the uppermost weathered portion of the vadose zone characterized by significant biological activity. Soil has a significant impact on the amount of recharge which can infiltrate into the ground.	2
	sand	9		
	peat	8		
	Shrinking and/or aggregated clay	7		
	Sandy loam	4		
	Loam Silty loam	5		
	Clay loam	4		
	Muck	3		
	Non-shrinking and non-	2		

	aggregated clay			
		1		
Topography (T) (slope%)	0-2	10	Refers to the uppermost weathered portion of the vadose zone characterized by significant biological activity. Soil has a significant impact on the amount of recharge which can infiltrate into the ground.	1
	2-6	9		
	6-12	5		
	12-18	3		
	>18	1		
Impact of vadose zone (I)	Silt/clay	1	Is defined as unsaturated zone material. The significantly restrictive zone above an aquifer forming the confining layers is used in a confined aquifer, as the type of media having the most significant impact	5
	shale	3		
	limestone	6		
	Sandstone	6		
	Bedded limestone, Sandstone, shale	6		
	Sand and gravel with significant silt and clay			
		6		
	Metamorphic/igneous	4		
	sand and gravel	8		
	Basalt	9		
	Karst limestone	10		
Hydraulic conductivity (C) (mm/day)	1-100	1	Refers to the ability of an aquifer to transmit water, controlling the rate at which groundwater will flow under a given hydraulic gradient. material within the groundwater system	3
	100-300	2		
	300-700	4		
	700-1000	6		
	1000-2000	8		
	>2000	10		

Source: Environmental Protection Agency

3. RESULTS AND DISCUSSION

3.1. Depth to Water Table

Depth to water table layers map in the Gilan central plain based on DRASTIC Model is shown in Figure 1. The distance of the depth to water table ranges from 4.5 m in the central parts to less than 1 m in the north-west and eastern parts of the plain. Central Plain' aquifer can be divided into two zones which are shown with two different colors in the map (Figure 1) the yellow zone, which encompasses a large area of central, northern and southern parts of the Plains. Depth to water table in this zone ranges from 1.5 to 4.5m and has a rating of 9 in the DRASTIC Model. And 2) the blue zone, zone, which covers the northwest, northeast, East and small areas of central and northern parts of the plain. Depth to water table in this zone ranges from 0 to 1/5 m and has a rating of 10 in the DRASTIC Model.

3.2. Net Recharge

The net recharge map of the plain based on DRASTIC Model is shown in Figure 2. This map was prepared based on three overlapping components, amount of annual rainfall, slope, and soil permeability according to Piscopo [10]. The aquifer was divided into 4 zones which are ordered as follow in terms of their areas in the plain: 1) The green zone with the highest net recharge (>250) which covers a great part of the plain; 2) The red zone with the net recharge range from 100 to 800 which encompasses parts in the northern, northern west, western and southern plain; 3) The pale blue zone with a net recharge range of 180-250. The recharge in these three zones is most affected by high rainfall and permeability of the plain. According to the DRASTIC Model, the ratings 6 to 9 are assigned to these areas.

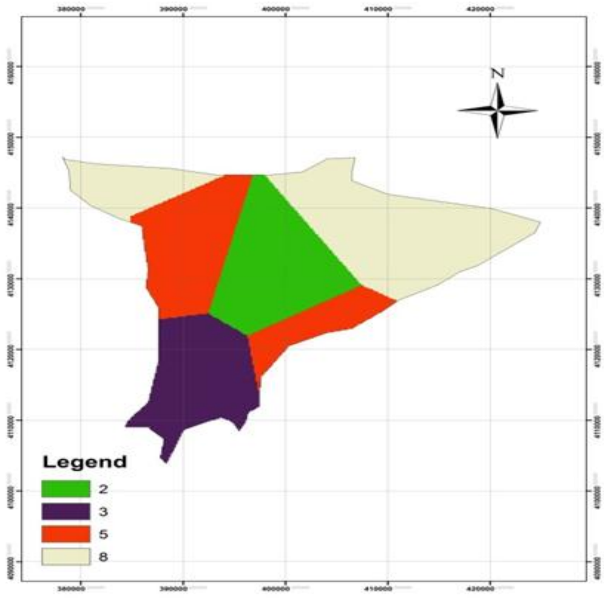

Figure-1. Depth to water table layers map

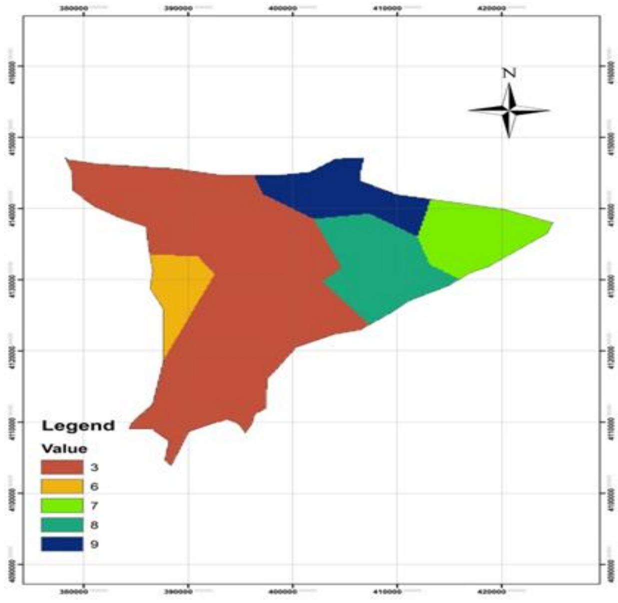

Figure-2. The net recharge map

Source: Generated by author

3.3. Aquifer Media

The aquifer media map of the central plains prepared using information obtained from exploratory drilling and geophysical studies in the plain is shown in Figure 3. The aquifer of the plain was divided to 4 zones with different colors on the map in terms of the aquifer media. Gray zone, which includes the northern, northern west and eastern parts and is constituted from the medium-grained sediments to coarse gravel and a major sedimentary part. The rating 8 was dedicated to this zone based on DRASTIC Model. Red zone covers parts of northern and western plain including glacial sediments and a rating of 5 was assigned to these parts. Green zone, including parts of northern and central plain formed from the mass shale and has been rated 2 in the DRASTIC Model. Finally, the blue zone included parts of southern and southern west aquifer containing igneous and metamorphic formations and was rated 3 in DRASTIC Model.

3.4. Soil Media

The layering map of soil media based on DRASTIC Model shown in Figure 4. The soil layer indicates 2 types of soil gradation and 5 different classes. The first type, coarse-grained soils with a sandy loam texture and a rate of 6 which include the northern, eastern and a part of the western plains. The second type, clay loam soils with a rate of 3 which include the northwest, all central and southern parts with less permeability. Thus, pollutants transfer into the groundwater system is decreased in these parts.

3.5. Topography

The topography rating map of the Gilan central plain based on DRASTIC Model is shown in Figure 5. Almost the entire study area except for a small part in the southern plain with a slope of 2 to 6% which is shown in blue and a rate of 9 on the map has a slope of less than 2 percent which is determined in DRASTIC Model with a rate of 10. Thus, it can be said that the slope of the plain is low. It increases the pollution potential of groundwater.

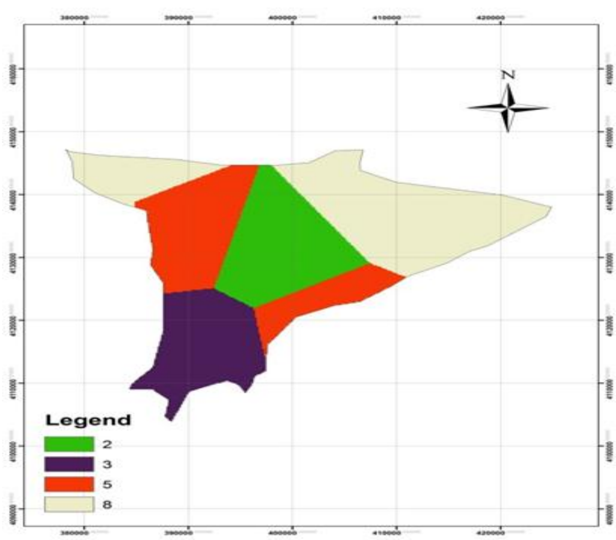

Figure-3. The aquifer media map

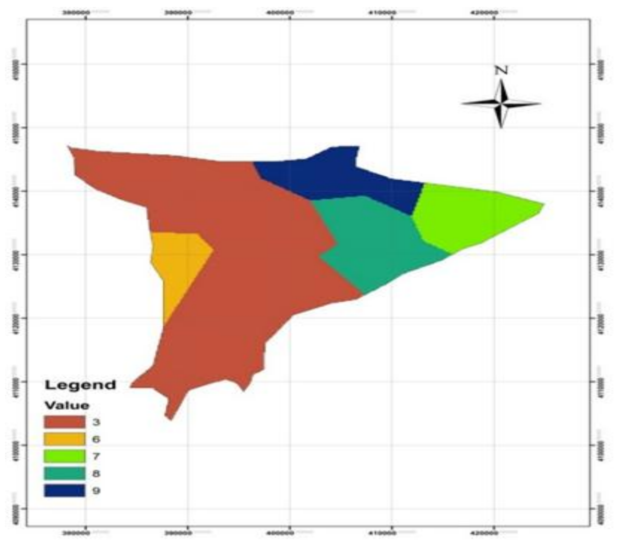

Figure-4. The layering map of soil media

Source: Generated by author

3.6. Impact of Vadose Zone

According to hydrological studies in the region based on existing well logs, unsaturated zone (vadose) sediments in the aquifer are diverse. The layout map of the vadose zone used in the model is shown in Figure 6. According to this map, three zones were visible in the central plains. Red zone covers western and central parts of the plain including sand, gravel, a major part of silt and clay. The typical rating assigned to these areas was 6. Yellow zone encompasses northwestern, a part of central, southern, and eastern plain has higher extent containing finer texture such as clay silt and shale and a rate of 3 was assigned to these areas. In addition, the blue zone includes parts of north, north eastern and eastern Gilan central plains and consists of sand with a rating of 8 is the DRASTIC Model.

3.7. Hydraulic Conductivity

Figure 7 shows the hydraulic conductivity rating map. According to the Figure 7, the plain was divided into 4 specified areas. The first area has the least hydraulic conductivity (less than 5.5 m per day), in purple includes north,

north-west, west and south parts of the plain, which has the lowest rate of vulnerability, 1 according to DRASTIC Model. The second area or green zone covers the major parts of the central plain with a hydraulic conductivity between 5 and 15 m/day and a rate of 2. The third area, the blue zone includes the central part of the Gilan central plain with a hydraulic conductivity from 15 to 35m/day and a rating of 4 in DRASTIC Model. Finally, the yellow zone covers a small area in the northeastern Gilan central plains with a hydraulic conductivity ranges from 35 to 50 m/day, a rate of 6 in the DRASTIC Model and the high transmission rate of pollution.

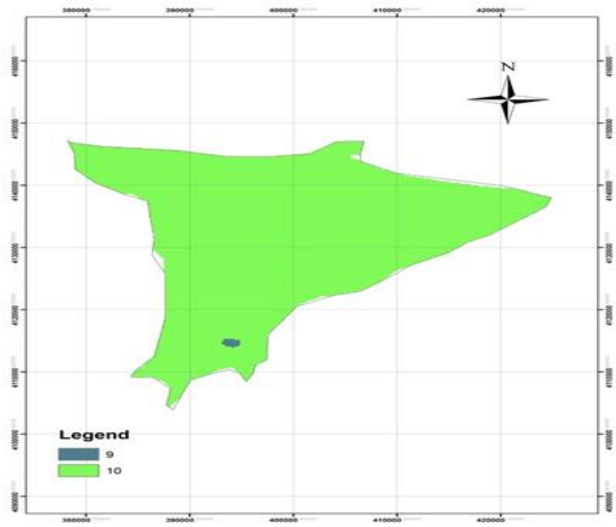

Figure-5. The topography rating map

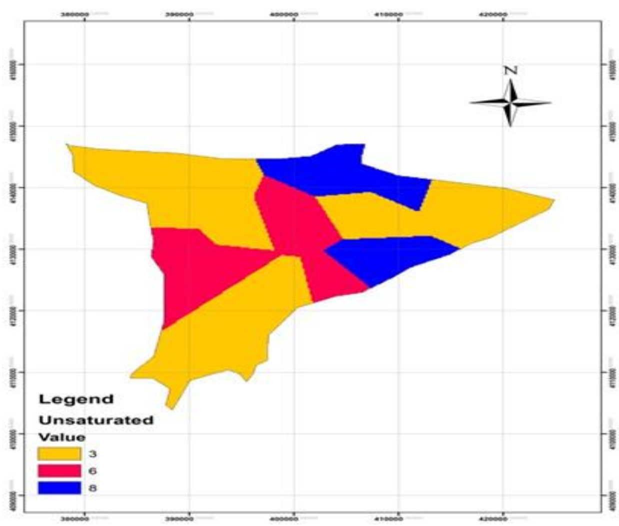

Figure-6. The layout map of the vadose zone

Source: Generated by author

3.8. Calculation of Vulnerability Index of DRASTIC Index:

Figures 8 and 9 show DRASTIC Index map and aquifer vulnerability map based on DRASTIC Model, respectively, which obtained overlapping seven above components. Based on the vulnerability classification in DRASTIC Model, the study area was categorized in three vulnerability classes according to Table 3.

Table-3. Vulnerability and drastic index

Vulnerability	Drastic index	Area(km^2)	Area (%)
low	47-92	6.9	0.81
moderate	93-136	430.9	50.55
high	137-184	414.6	48.64
total	-	852.4	100

Source: Calculated using Primary data

According to these maps, DRASTIC Index ranged from 89 to 182. The map showed the large extent of the areas with high vulnerability (48.64%) and areas with medium vulnerability (50.55%) in the region. According to the map, the northeastern, eastern and parts of the central plain have high vulnerability potential to contaminants and contaminated waters. However, only a small area of the plain (0.81%) has low vulnerability. Probably, more vulnerability is because of high water table, low slope of the area, high recharge rate, and coarse sediments in the vadose and saturation zones.

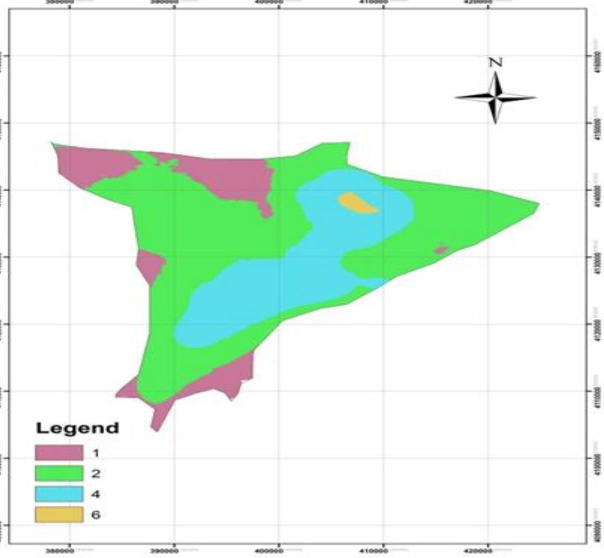

Figure-7. The hydraulic conductivity rating map

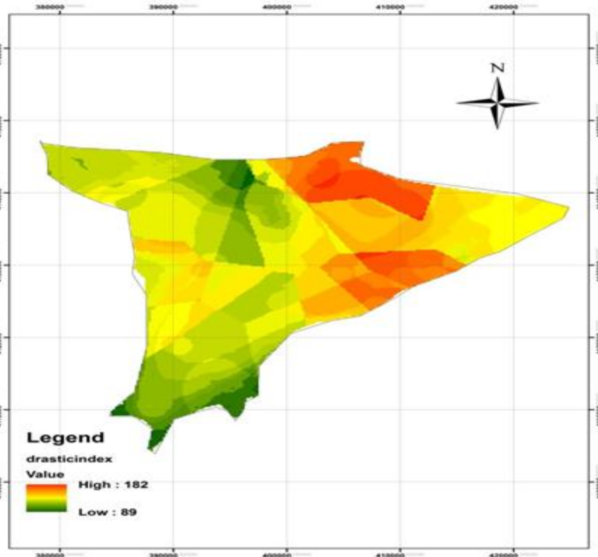

Figure-8. DRASTIC Index map

Source: Generated by author

3.9. Examination the Status of Nitrate Pollution in the Region

The average concentration of nitrates in the study wells in the Guilan Central Plain is 8.92 mg/l. Nitrate concentration in all studied wells is less than recommended level by U.S. Environmental Protection Agency (45 mg/l). However, the minimum nitrate concentration is above zero, which indicates the presence and penetration of nitrate to all wells in the plain or to all parts of the plains. The nitrate concentration of 48% of samples ranged from 1 to 3.6 mg/l, while, more than 60% of samples had a nitrate concentration less than 10 mg/l. The iso-concentration map of nitrate was shown in Figure 10. Increased nitrate levels in wells in the study area was predictable due to the high and medium vulnerability potential for a large part of the region, continued and uncontrolled discharge of nitrate, especially through industrial activities and agricultural fertilizers into the plain. It seems that the main source of nitrate in groundwater in the Guilan Central Plains is agricultural activities. The use of chemical fertilizers, especially urea in rice cultivation, use of animal manure to improve soil quality in rice paddies and farmlands are the most common ways for nitrate entering into groundwater.

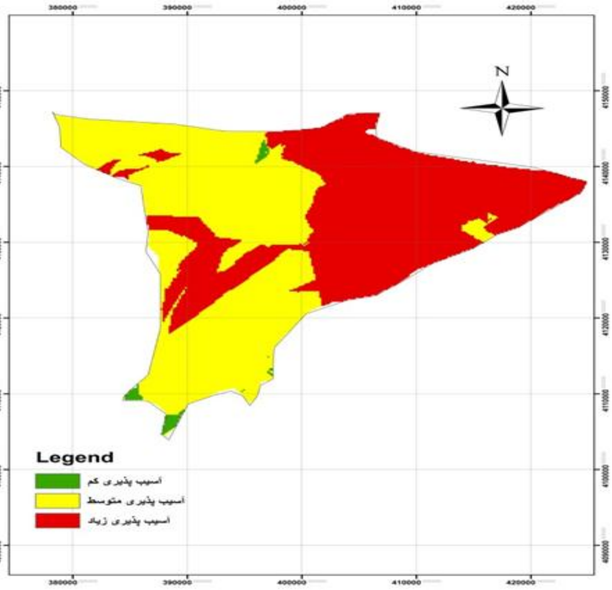

Figure-9. Aquifer vulnerability map

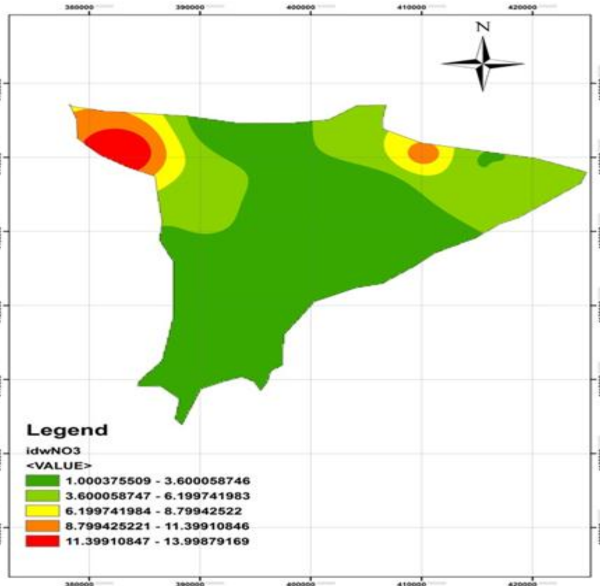

Figure-10. The iso-concentration map of nitrate

Source: Generated by author

3.10. Verification of DRASTIC Model in the Region

Red and yellow colors in the iso-concentration map of nitrate indicated existence of this element in all areas of the plain with high and medium potential for vulnerability. This could be due to consistent of vulnerability map and nitrate iso-concentration map. DRASTIC Model validation in the region estimated the compliance of the nitrate concentration data with DRASTIC vulnerability layer of around 0.41. According to this correlation coefficient, it can be said that DRASTIC Model had proven acceptable. The correlation coefficient between the components of DRASTIC Model and nitrate layer was calculated to identify the most affecting component on the groundwater contamination in the study plain and the results were presented in Table 4. The factors, depth to water table and vadose zone were more correlated to the nitrate layer. The factors, net recharge, and soil media were more correlated to the nitrate layer than the hydraulic conductivity, topography and aquifer media. According to the results, the factor, depth to water table has the strongest correlation to nitrate layer, which confirmed the results of the model sensitivity analysis.

Table-4. The correlation coefficient between the components of model and nitrate layer

parameter	correlation coefficient
D	0.21
R	0.15
A	0.07
S	0.14
T	0.11
I	0.19
C	0.08

Source: Calculated using Primary data

3.11. Sensitivity Analysis of DRASTIC Model in the Region

It could be possible to identify the most effective vulnerability factors using a sensitivity analysis and then, to examine how deal with the pollution and aquifer crisis management, accordingly. In this study, two methods, map removal sensitivity analysis and single component sensitivity analysis were used.

3.11.1. Map Removal Sensitivity Analysis

The results of the map removal sensitivity analysis and variability of the vulnerability index for DRASTIC Model are shown in Table 5. The main affecting factors on the vulnerability index for DRASTIC Model were depth to water table and vadose zone (mean variations index were 25.1% and 22.1%, respectively). In DRASTIC, the components, depth to water table and vadose zone had a standard deviation higher than other components. It seems that there will be significant variations in the model results due to the extreme sensitivity of vulnerability index in DRASTIC Model to removal of these components. In addition, the least affecting factor in DRASTIC Model is topography (a mean variations index of 8.5%). DRASTIC Model did not show any sensitivity to remove this component in this area.

Table-5. Sensitivity analysis and variability of the vulnerability index

parameter	mean	Standard Deviation
D	25.1	23.2
R	16.4	8.4
A	17.5	7.6
S	20.6	8.9
T	8.5	4.4
I	22.1	15.5
C	15.8	5.1

Source: Calculated using Primary data

Single component sensitivity analysis: Single component sensitivity analysis was conducted to assess the impact of each component on the Vulnerability Index. This analysis compared effective and theoretical weights of the components. Table 6 shows a summary statistics of single component sensitivity analysis for DRASTIC Model. The table showed that the effective and theoretical weights of the DRASTIC model components didn't match fully, and in some cases are significantly different. The factors, depth to water table and vadose zone with average effective weights of 23.7% and 22.1%, respectively were considered as the most affecting factors in vulnerability assessment by DRASTIC Model. It confirmed the results of map removal sensitivity analysis. The average effective weight of these components is slightly more than the theoretical weight assigned to them in the DRASTIC Model. The factors, soil media, topography, and net recharge showed a higher effective weight than the theoretical weigh. However, the components, aquifer media, and hydraulic conductivity showed less effective weight than the theoretical weight in DRASTIC Model. The factors, aquifer media, and hydraulic conductivity had less impact on the vulnerability of Gilan Central Plain compared to the DRASTIC model assumptions. While, the factors, depth to water table, vadose zone, soil media, topography and net recharge had greater impact on the potential of groundwater contamination in Gilan Central Plains than the model assumptions. The most effective factors in vulnerability assessment had the highest standard deviation. According to the results, the component, depth to water table was the most effective factor in the vulnerability. Therefore, in the case of agricultural and industrial development, or any harmful activity in the plain, the component, depth to water table should be considered more than other components, and related planning should be done with an emphasis on the greater impact on this component.

Table-6. Summary statistics of single component sensitivity analysis

parameter	The theoretical weight	The theoretical weight (%)	mean	Standard Deviation
D	5	21.7	23.7	11.2
R	4	8.4	9.4	5.4
A	3	13.5	10.2	5.6
S	2	17.4	19.1	4.9
T	1	8.5	10.5	2.4
I	5	21.1	22.1	8.5
C	3	12.8	6.8	2.1

Source: Calculated using Primary data

4. CONCLUSION

The significant point and non-point sources of pollutants resulting from human activities above ground and penetration of pollutants into the aquifer reduce groundwater quality. Therefore, avoiding from the groundwater contamination is essential in management of these water resources. One of the best strategies to prevent groundwater pollution is determination of the aquifer vulnerability and leading the management efforts toward these areas in order to maintain water quality. Thus, in this paper, the vulnerable areas in Gilan Plain aquifer were identified using DRASTIC Model. This model was run in GIS environment. To verify model results, nitrate concentration of water samples taken from a number of wells in the plains was measured. The index obtained from DRASTIC for the aquifer of Guilan central plain ranged from 82 to 182. Very high or very low vulnerabilities were not observed in this plain. The final map of DRASTIC Model showed that a large extent of the area has high vulnerability (48.64%) and 50.55% of the area was with medium vulnerability and only a small area of the plain (0.81%) has low vulnerability. The vulnerability index could be used to make decisions about land management, fertilizer application, industries site selection, etc. It can be said based on the final vulnerability map that development of industrial and agricultural activities should be implemented with management and high precision because of the high vulnerability potential of the area. Statistical summary of the DRASTIC Model components showed that depth to water table has the highest impact on the DRASTIC Model. In addition, according to map removal and single component sensitivity analyses, depth to water table was identified as effective component in the Gilan central plain. The results of the correlations between the components of DRASTIC Model and nitrate ion suggested that the highest correlation is between nitrate ion and depth to water table. Therefore, in the case of agricultural and industrial development, or any harmful activity in the plain, the component, depth to water table should be considered more than other components, and related planning should be done with an emphasis on the greater impact on this component. Due to the high and medium vulnerability potential of the study area, industrial and agricultural practices, particularly the use of chemical fertilizers must be controlled to prevent further contamination of groundwater. According to the results of the DRASTIC Model in this study and many national and international studies, as well as its low cost, it is suggested that this method might be used in the province and other parts of the country to manage aquifers in order to prevent contamination. One of the DRASTIC Model disadvantages is that the parameters classification and valuation are based on expert judgment. It therefore leads to uncertainty in the results. To solve this problem it is suggested that the research be carried out on specific vulnerability to common pollutants such as nitrate, pesticides, etc. and DRASTIC Model be calibrated. It is recommended that vulnerability assessment be also performed using fuzzy logic and neural network techniques and their results be compared with DRASTIC Model and the actual data. It may contribute to improve vulnerability assessment or to identify the best way to vulnerability assessment.

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