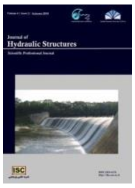
Journal of Hydraulic Structures
J. Hydraul. Struct., 2025; 11(2): 87-105
DOI: 10.22055/jhs.2024.47643.1316



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Investigating the vulnerability of underground water to pollution (case study: East and Northeast of Chaharmahal and Bakhtiari province)

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Abstract

Groundwater aquifers, as one of the most important and vulnerable water resources, are exposed to pollution in various ways, and the detection and control of pollution in them is more difficult and costly than surface water. Also, due to the persistence of pollution in these sources, the best way to prevent their pollution is to identify polluting sources and vulnerable sources, prepare vulnerability zoning maps and adopt appropriate management policies. Considering the importance of the existing aquifers in the east and northeast of Chaharmahal and Bakhtiari province as a supplier of drinking water and agriculture in Barzagi sector of Shahrekord, Farsan, Borujen and Kiyar cities, this research aims to identify the vulnerable areas of the mentioned aquifers using DRASTIC model was done in GIS environment. Then validation was done using the available data. The results showed that the vulnerable classes were: low pollution 42.71%, very low 33.53%, low to medium 17.83%, no pollution 4.07%, medium to high 1.57% and high 0.29% covers the area.

Keywords: risk assessment; DRASTIC model; special vulnerability; Chaharmahal and Bakhtiari.

Received: 03 August 2024; Accepted: 25 October 2024

1. Introduction

Groundwater is considered as an important source of water resources due to its low pollution potential and high storage capacity compared to surface water. The presence of pollutants caused by human activities on the surface of the earth and the penetration of these pollutants into the aquifer reduces the quality of underground water, for this reason it seems necessary to prevent the pollution of groundwater [1]. One of the appropriate tools that helps effectively in groundwater management is the preparation of maps in which vulnerable or sensitive areas to pollution are identified. In this way, different areas can be compared with each other and have a single criterion for evaluation. There are different methods to determine the vulnerability

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potential of the groundwater table, including overlapping methods, mathematical methods, statistical methods and combined methods. The overlapping methods are based on combining the layers obtained from different parameters and have the same working basis. These methods differ in the use of the type and number of parameters, but ultimately lead to recording a numerical index or score for each feature [2]. One of the most practical overlapping methods is the Drastic method, which was provided by the US Environmental Protection Agency to determine the potential of groundwater [3]. In this research, the DRASTIC model is used to evaluate the potential of groundwater pollution in the eastern and northeastern regions of Chaharmahal and Bakhtiari provinces.

Checha Ramhal and Bakhtiari province with an area of 16,532 square kilometers is located in the southwest of the country, in the east and northeast of this province are Shahrekord, Farsan, Kiyar and Borujen counties. The suppliers of drinking water and agriculture in a large part of the province are located in the mentioned cities [4]. In recent years, the increase in population and the consequent increase in water demand, as well as the decrease in the quality and pollution of groundwater due to the development of industry and agriculture, have caused attention to the quality of groundwater resources. One of the appropriate ways to prevent groundwater pollution is to identify vulnerable aquifer areas and manage the exploitation of water resources and land use. Changing the quality of groundwater is a big risk for the development of agriculture, animal husbandry, tourism and economy of the province. Considering the importance and necessity of this matter in this research, the zoning of the vulnerability potential of the aquifers is done using the DRASTIC model in the GIS environment.

The DRASTIC model was first introduced in 1987 by Aller and the US Environmental Protection Agency developed it in 1990 to be used as a standard system for assessing groundwater contamination potential [5]. DRASTIC model is one of the most practical overlapping methods. The term DRASTIC stands for parameters that control groundwater pollution in the hydrogeological system. These parameters include: groundwater depth (D), recharge (R), aquifer constituents (A), soil type (S), topography (T), effect of unsaturated zone (I) and hydraulic conductivity of the aquifer (C). Groundwater determines the depth that the pollutant must travel to reach the water table and is very important [6]. Net nutrition is a very important factor for the penetration and transfer of pollutants from the unsaturated zone to the saturated zone, and it takes solid and liquid pollutants to the groundwater level and can also increase the water level [7]. The aquifer environment includes empty spaces and fractures that hold and pass water, so the ingredients of the aquifer affect the flow inside it [8]. The soil environment is called the weathered part above the unsaturated zone. This part is very important in terms of biological activities and the presence of organic substances, and it has a high power to remove and reduce the concentration of pollutants [9]. Topography refers to the changes in the slope of the land, which controls the pollutant movement and its retention on the land surface [10]. The unsaturated environment includes the part located between the water table and the soil environment, which is essentially unsaturated or discontinuously saturated [11]. Hydraulic conductivity shows the ability of aquifer materials to transport water. The movement and diffusion of water and pollutants in the aquifer is controlled by hydraulic guidance [12]. The DRASTIC model is based on the following four assumptions that should be considered for choosing the study area. 1- Contamination enters the groundwater from the surface of the earth. 2- The pollution is washed away by rain and enters the underground water. 3- Transfer of pollution through water and at a similar speed. 4- The area studied under the DRASTIC system must have an area of more than 40 hectares [13]. Finally, after collecting and digitizing the hydrogeological information, the seven mentioned factors that control the pollution potential.

They are overlapped and combined to prepare a vulnerability map, and a new layer named DRASTIC index is obtained.

In recent years, the evaluation of groundwater has been done by researchers in the world and in Iran with several methods, which shows the importance of this issue, which is mentioned in some studies. Siganga et al. (2023) in a study entitled the assessment of groundwater vulnerability in a region in Kenya using the drastic method concluded that Maraka region and Muchi town are more vulnerable than the rest of the studied regions [14]. Ansari and Jabbari (2023) in the article assessing the vulnerability of the aquifer in a semi-arid region of Iran (Izadkhash Fars Plain) announced that almost 50% of the plains were in the high vulnerability class and 28% were in the very high vulnerability class. Places with high vulnerability to pollutants and polluted water were observed in the east and center of the plain. The influence of the formations in the east of the basin can be seen because the amount of sulfate has increased sharply at the outlet of the rivers in the east of the basin, which indicates the presence of evaporite formations with chalk. In the center of the basin, the heavy texture of the soil, low slope and more accumulation of water entering the basin, some of which have a lot of salts, have increased the vulnerability of this part. Another result of this study is that the DRASTIC model is highly effective in evaluating vulnerabilities similar to this research [15]. Among the reasons for the differentiation and innovative aspects of this research compared to similar cases, we can mention: the vast extent of the study area (four major cities of the province including: Shahrekord, Borujen, Farsan and Kiyar) mentioned. On the other hand, nitrate and groundwater quality index have been used to validate the drastic model. To calculate the groundwater quality index, the standards of the Iranian Institute of Standards and Industrial Research and the standards of the World Health Organization have been considered.

2. Materials and ways

2.1. The study area

Chaharmahal and Bakhtiari province with an area of 16533 square kilometers and an average height of 2668 meters in the range between 31 degrees 14 minutes to 33 degrees 47 minutes North latitude and 49 degrees 49 minutes to 51 degrees 34 minutes East longitude in the southwest of the Iranian plateau and the central part Zagros mountain range is located. Figure 1 shows the location of Chaharmahal and Bakhtiari province. Shahrekord, Farsan, Kiyar and Borujen cities are located in the east and northeast of this province [16]. The aquifers of Shahrekord, Farsan, Kiar, Shalamzar, Sefidasht, Boruj and Gandaman-Beldaji, which supply drinking and agricultural water to a large part of the province, are located in the mentioned cities.

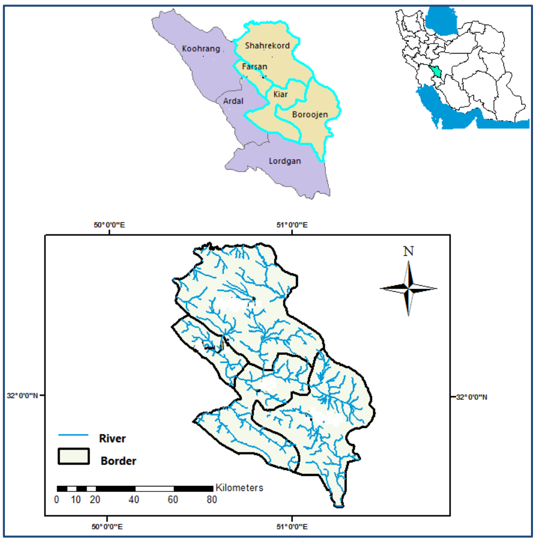

Figure 1. Location of the study area

2.2. Data collection and preparation

The present research is descriptive and analytical in terms of type and practical in terms of purpose. This research was carried out through the steps of: collecting the required data and information and preparing standard maps, assessing the vulnerability potential of Alogi using the DRASTIC model and validating the DRASTIC model. For this purpose, the available statistics and information were entered into the GIS database. From various information sources, including topographic maps with a scale of 1/50000 and land use and geological maps with a scale of 1/100000 of the National Geological Organization, soil map, meteorological statistics, hydrology, groundwater level, results of pumping tests, drilling logs Observational, exploration and exploitation wells, maps of geophysical studies and statistics of water resources were used. These data were obtained from organizations such as Iran Resources Management Company, Provincial Regional Water Company, Provincial Agricultural Jihad Organization and Soil and Water Research Institute. Map information (such as topographic and geological maps) after being digitized and tabular information such as groundwaterlevel, was converted into information bank format and entered into the database, and ArcGIS 10.5 software was used to prepare the required layers. In order to evaluate the vulnerability of groundwater pollution, 7 layers of information including groundwater depth, net nutrition, aquifer environment, soil environment, slope, unsaturated environment and hydraulic conductivity of the aquifer were used. In order to prepare the depth layer to the water level, the statistics and information of 150 piezometric wells in the area were used. To prepare the slope map, a digital topographic map of the area with a scale of 1/100,000 along with auxiliary elevation points related to observation wells was used. The obtained topographic map was converted into a raster and then the slope value was calculated for each cell. Piscopo (2001) method was used to prepare the feeding layer. Piscopo replaced the nutrient potential of an area based on the amount of rainfall, topography and permeability of the area, replacing the method provided by the United States Environmental Protection Agency. To calculate the amount of nutrition, the slope is extracted from the digital elevation model of the area and using the criteria in table (1) was classified.

Table 1. The method of rating the effective slope factor in net feeding [17]

Parameter	Slope%
4	<2
3	2-10
2	10-33
1	33<

Permeability map was also prepared and classified according to the soil hydrology group of the region and according to the criteria defined in table (2) and table (3).

Table 2. minimum infiltration intensity in soil hydrological groups [18]

Soil Hydrological groups	Soil Type	Penetration Rate
A	Sand and gravel	High
B	loamy sand-clay	Medium
C	sand	
D	Lumi	low
	Clay, saline soils, stone	very low

Table 3. Method of rating effective soil permeability factor in pure nutrition [19]

Parameter	Permeability
5	High
4	Medium -
3	High
2	Medium
1	low
	very low

Then, using the data obtained from meteorology, the precipitation map of the studied area was prepared and classified according to table (4).

Table 4. Method of rating effective precipitation factor in net feeding [20]

Parameter	Rainfall(mm)
4	850<
3	700-850
2	500-700
1	<500

After preparing the mentioned maps, in order to obtain net nutrition, all three maps of slope, infiltration and rainfall of the area were overlapped and net nutrition was obtained from equation (1).

Relationship (1) amount of nutrition = % slope + amount of rainfall (mm) + amount of permeability (mm) And finally, the nutrition map was ranked using table (5).

Table 5. Net nutrition ranking method [21]

Rank	Range
10	11-13
8	9-11
5	7-9
3	5-7
1	3-5

The aquifer environment and its ingredients determine the length and trend of the groundwaterflow system in the aquifer. The coarser the materials are, due to the higher permeability of these materials, the vulnerability potential of the aquifer will be higher [22]. To prepare the aquifer layer, the logs of observation and exploitation wells in the region were used. First, the geology map was introduced to the ArcGIS environment and the Eliminate command was performed to remove small areas, then according to the type of log wells (from the reservoir level to the bedrock) or the numerical value based on table (6) was entered in the field created in the geology map. and after that the Dissolve command was executed to unify the common codes, and finally, with the polygon to raster command, the vector map was converted to raster and the final map of the aquifer environment was obtained.

Table 6. ranges and ratings related to the aquifer environment [23]

Range	Rank
Massive shale	2
Igneous/metamorphic	3
Igneous / weathered	4
metamorphism	5
Frosts	6
Layered sandstone,	6
limestone	6
Massive sandstone	8
Massive limestone	9
basalt	10
Limestone	

The soil environment means the upper part of the unsaturated zone, which continues until the penetration of plant roots or the activity of organic organisms. The potential of soil pollution depends on soil characteristics such as soil texture, permeability, and soil organic matter percentage [24]. The soil map of the area was produced according to the land use map and using the existing soil maps of the area in the GIS environment, and the soil environment layer was produced and stored as a raster layer and classified using table (7).

Table 7. Ranges and rankings of soil texture type [25]

soil pattern	Rank
Narc or	10
lack of soil	10
layer	9
Sand	8
sand	7
plant	6
fertilizer	5
dense clay	4
Sandy loam	3
loam	2
Silty loam	1
clayey	
loam	
Fertilizer	
loose clay	

Milder slopes provide the opportunity and possibility of more contamination penetration along with rainfall and in this way, create more pollution potential. Therefore, in the DRASTIC model, areas with a lower slope are ranked higher. The important role of topography can be mentioned in the development and evolution of soil. So that in steep slopes compared to gentler slopes, the thickness of the surface soil layer is less. Therefore, topography by affecting the soil development also affects the pollution potential [26]. In order to prepare the slope layer, using the digital elevation model map of the region in the ArcGIS environment, in the Spatial Analyst section, using the slope determination tool, this layer was prepared and classified and weighted according to the standards and criteria defined in table (8).

Table 8. Slope ranges and ratings [27]

Slope %	Rank
0-2	10
2-6	9
6-12	5
12-18	3
18<	1

The unsaturated environment refers to the lower part of the topsoil up to the water table. The unsaturated environment layer, similar to the soil layer, affects the pollution potential, and the extent of its effects is a function of the permeability and characteristics of the environment of the unsaturated zone. In the unsaturated part, the type of the unsaturated zone and the ability to absorb and retain pollutants and the texture of the geological materials present in it are taken into consideration. Fine particles in clay have greater absorption and retention power than coarse particles and prevent the movement of pollutants into the waters. It is underground and reduces the potential of aquifer pollution. To prepare this layer, exploratory and observational well logs were used, and a similar method was used to prepare the aquifer environment layer, with the difference that for the unsaturated environment layer, the thickness and material of the layers of the unsaturated zone in the well logs have been considered. To prepare the mentioned layer, first introduce the geology map to the ArcGIS environment and execute the Eleminate command to remove small areas, then, according to the type of well logs, enter a numerical value based on table (9) in the field created in the geology map and the Dissolve command to merge The common codes are executed and finally, with the polygon to raster command, the vector map is converted to a raster and the final map of the unsaturated environment is produced and multiplied by five (layer weight) in the raster calculator part of the ArcGIS environment. The high weight of this layer is because the area Unsaturated by retaining, absorbing and removing pathogenic viruses and bacteria, absorbing and reducing many synthetic organic chemicals, diluting the concentration of heavy metals and other inorganic chemicals through absorption and reaction with the surface of minerals in the unsaturated zone and through Plants and agricultural products play a key role in protecting groundwater.

Table 9. ranges and ratings of the unsaturated environment [28]

Range	Rank
Locking layer	1
silt/clay	3
shale	3
Limestone	6
Sandstone	6
Limestone and Layered	6
shales	6
	4
Sand with a large amount	8
of silt clay	9
Igneous/metamorphic	10
Sand	
basalt	
Karst limestone loose clay	

The hydraulic conductivity of an aquifer shows the mobility capacity of groundwaterin a saturated environment, therefore, the potential for the mobility of polluting substances by groundwateris almost equal to the hydraulic conductivity of the aquifer [29]. The amount of hydraulic conductivity controls the pollutant's movement and spread from the point of infiltration until it reaches the saturated zone. For this reason, areas with high hydraulic conductivity create more pollution potential. The information related to hydraulic conductivity is obtained from the calculations of the pumping test of the existing wells in the study area. Considering that in the pumping tests, the value of the transferability coefficient parameter is measured, the information and geographical location related to the transferability coefficient and saturation thickness The aquifer of the studied area was obtained from the reports prepared by the water district administration. Then, the transferability coefficient map was obtained on the aquifer thickness map according to equation (2) and the hydraulic conductivity map of the area was obtained and it was classified according to the criteria defined in table (10).

Equation (2) $T=Kb$ In this relation, K is the hydraulic conductivity in terms of (m/D), b is the thickness of the aquifer in terms of (m) and T is the transfer coefficient in terms of (m^2/D).

Table 10. ranges and ratings of hydraulic conductivity [30]

Range(m/Day)	Rank
0.04-4.1	1
4.1-12.3	2
12.3-28.7	4
28.7-41	6
41-82	8
82<	10

Finally, after collecting and digitizing the hydrogeological information, the seven mentioned factors that control the pollution potential. They were overlapped and combined to prepare the inherent vulnerability and a new layer named DRASTIC index was obtained. Therefore, the inherent vulnerability index in this method was obtained by multiplying the weight of each parameter by its rank [31]. The classification and valuation of the classes related to each of the parameters was done based on the DRASTIC standard method in the GIS environment in the Raster calculator section. A larger DRASTIC index indicates a greater sensitivity of the area to pollution, and a smaller number indicates a lower sensitivity. Finally, by ranking the DRASTIC index based on table (11), the vulnerability map of the region was prepared.

Table 11. ranking of DRASTIC vulnerability index [32]

Index value	Vulnerability class
<79	No risk of
80-99	contamination
100-119	very little
120-139	Low
139-159	low to medium
160-179	Moderate to high
180-199	Much
199 <	very much
	Quite susceptible

3. Discussion and results

The precipitation map of the studied area is shown in figure (2), the elevation map is in figure (3), the geological map is in figure (4) and the land use map is shown in figure (5).

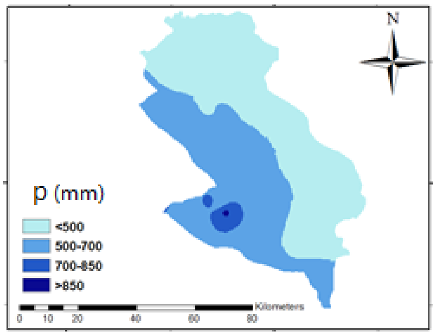

Figure 2. map of precipitation of the studied area

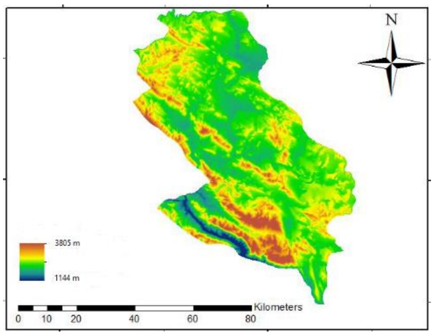

Figure 3. Elevation map of the studied area

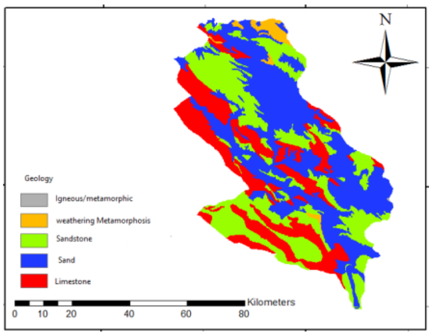

Figure 4. geological map of the studied area

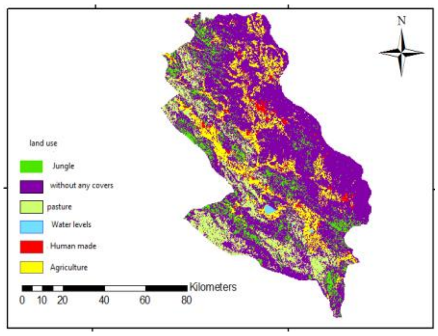

Figure 5. land use map of the studied area

In the studied area, the depth to the water table varies from 0.88 to 80.5 meters above the ground. The groundwaterdepth map is shown in Figure (6). The largest area of the studied area is related to the depths between 4.5 and 9 meters, which covers 24.82% of this area and in terms of vulnerability, it has assigned a value of 7. which has high ranks for vulnerability, and it can be said that the ability of the studied area in terms of the depth of the water table to be polluted was high. In fact, the depth of groundwaterhas an opposite relationship with the level of vulnerability. The more the depth of the groundwaterdecreases, the greater the vulnerability.

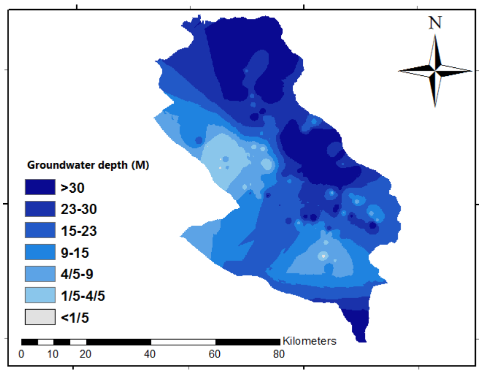

Figure 6. ranking the depth of the area in terms of pollution potential

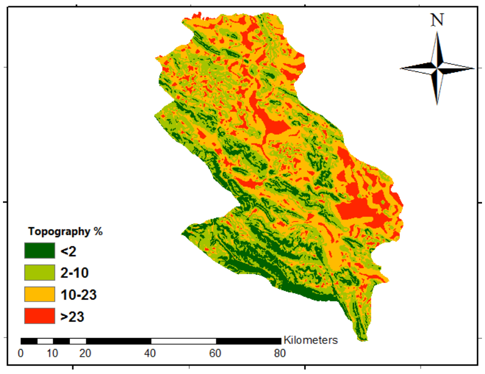

Figure 7. ranking of the slope map of the studied area

The slope map is classified according to table (1) and shown in figure (7).

Figure (8) shows the precipitation map of the study area. About 58% of the area has less than 500 mm of rainfall, and in the southwestern regions there are areas with more than 850 mm of rainfall. The higher the amount of precipitation, the higher the amount of nutrition, and this increases the vulnerability of the region to pollution.

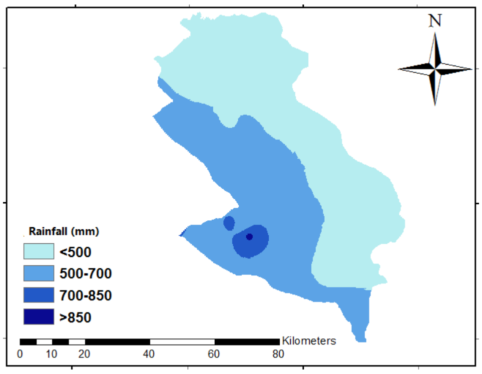

Figure 8. Rainfall ranking of the study area

Figure (9) shows the ranking of soil permeability of the study area. The lower the permeability, the less prone to contamination.

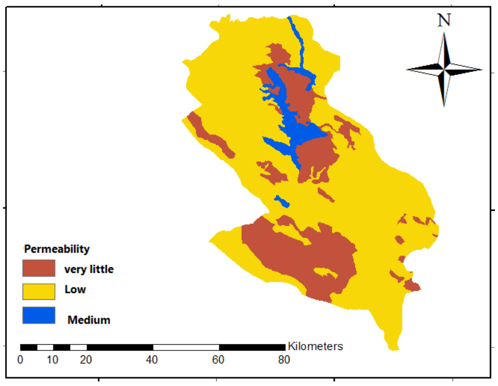

Figure 9. soil permeability ranking of the study area in terms of pollution potential

Figure (10) shows the map of net nutrition. Nutrition and vulnerability are directly related. As the amount of nutrition increases, the vulnerability also increases.

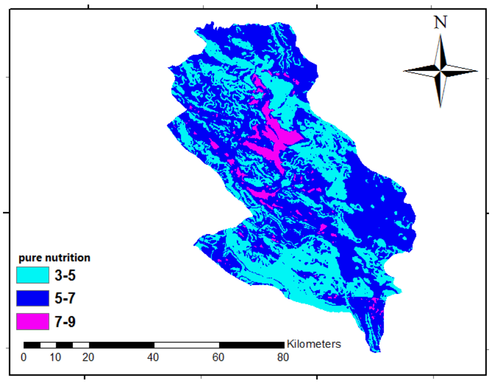

Figure 10. ranking of net nutrition of the study area

Figure (11) shows the zoning of the aquifer environment. According to the figure, up to 41.5% of the area of the area is related to sand and after that, sandstone covers up to 31% of the area.

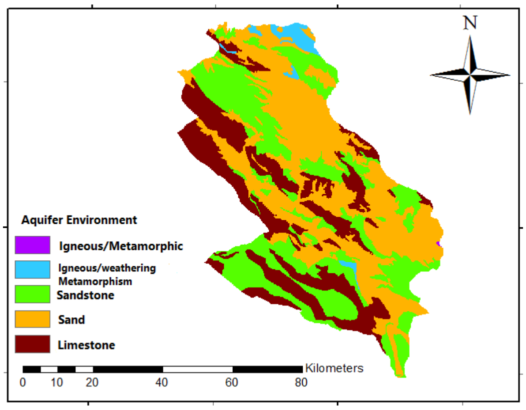

Figure 11. ranking of the aquifer environment of the study area in terms of pollution potential

Figure (12) shows the soil map of the region, according to which more than 50.8% of the area is related to loamy textures, 22.7% is non-dense clay and about 17.5% is clayey loam and according to table (7) respectively They have ranks 5, 1 and 3, and these tissues have low to medium ranks in terms of vulnerability. The texture of sand and gravel has a greater ability to transfer pollutants from the surface of the earth to the underground aquifers, which is small in the studied area.

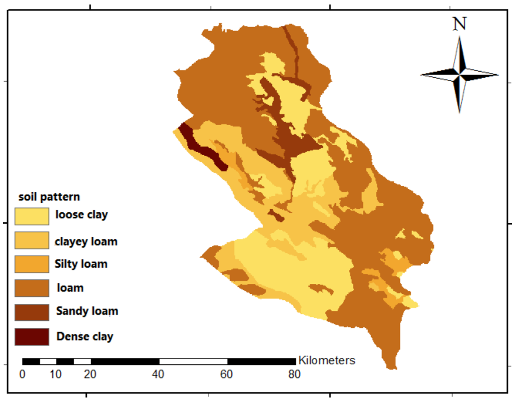

Figure 12. ranking of the soil texture of the study area in terms of pollution potential

Figure (13) shows the slope map. According to the figure, the largest extent is related to the slope of 0-2%, which according to table (8) is given the 10th rank in terms of vulnerability. In fact, slope and vulnerability have the opposite relationship. The lower the slope, the higher the vulnerability.

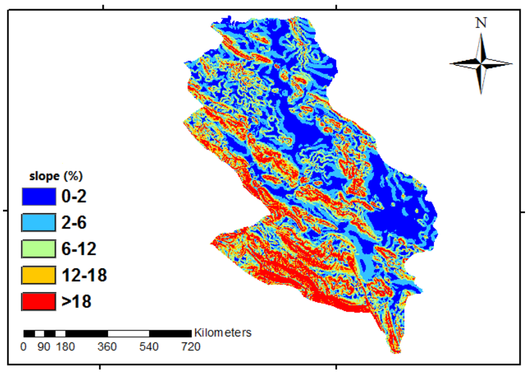

Figure 13. ranking of the slope of the study area in terms of pollution potential

Figure (14) shows the map of the effect of the unsaturated zone. According to the figure, the largest area with 51.3% is related to silt and clay and the smallest area is igneous and metamorphic with 2.54% of the area.

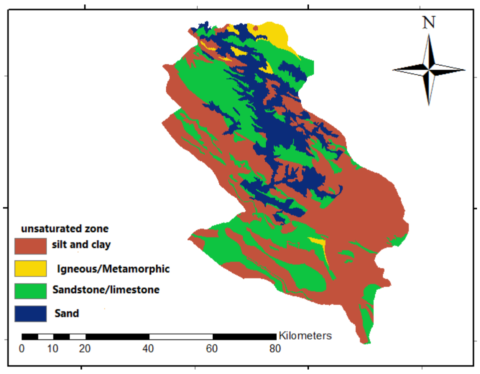

Figure 14. ranking the effect of the unsaturated zone of the study area in terms of pollution potential

The zoning map of hydraulic conductivity is presented in figure (15). According to the figure, about 83.6% of the area under study corresponds to rank 2 (12.3-4.1 meters per day). Hydraulic conductivity and the degree of vulnerability have a direct relationship. Vulnerability increases with the increase of hydraulic conductivity.

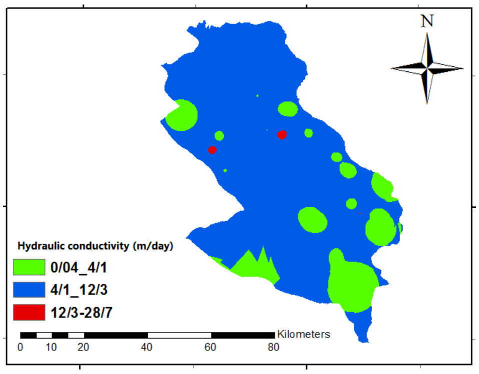

Figure 15. hydraulic conductivity rating of the studied area in terms of pollution potential

In Figure (16), the zoning map of inherent vulnerability is shown using the combination of seven drastic parameters, which classified the studied area into 6 categories: no pollution, very low, low, low to medium, medium to high, and high. These points should be taken into account when combining layers: a. All the created layers should be raster. b. Pixel size should be the same in all layers. J. All layers should be prepared in a similar coordinate system. According to table (12), the low vulnerability class has the largest area and the high vulnerability class has the least area. The three categories of low to medium vulnerability, medium to high and high pollution are mostly concentrated in the western areas of the study area. This indicates that there is more potential for vulnerability in the western areas and should be prioritized in pollution management planning. Take

Table 12. vulnerability classification of Drastic model and the area of each floor

Vulnerability class	Range of floors	area (km^2)	area (%)
No pollution	<79	296.11	4.07
very little	80-99	2437.56	33.53
Low	100-119	3104.86	42.71
low to	119-139	1296.53	17.83
medium	139-159	113.52	1.57
Moderate to	160-179	21.05	0.29
high			
Much			

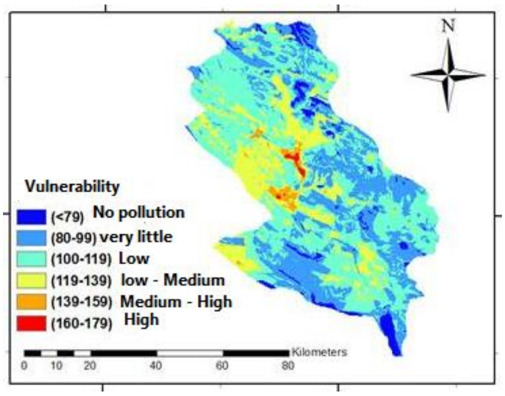

Figure 16. Inherent vulnerability zoning map using the combination of seven parameters

3.1. Validation of DRASTIC model using nitrate and GQI

Figure (17) shows the location of the wells where the nitrate parameter was measured on the DRASTIC pollution potential map. Figures (18) and (19) respectively show the location of the wells that the GQI obtained based on the standards of the Iranian Institute of Standards and Industrial Research and based on the standards of the World Health Organization. The final index calculated for the quality parameter of groundwaterin the region The studied item is above 80, which is in the good category based on table (13) of the groundwaterquality index.

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Table 13. ranking and value range in GQI [33]

Qualitative value of the index	Range
weak	<60
medium	60-80
Good	80<

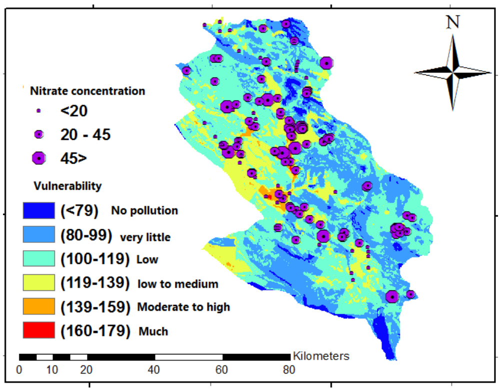

Figure 17. Drastic vulnerability map and nitrate concentration

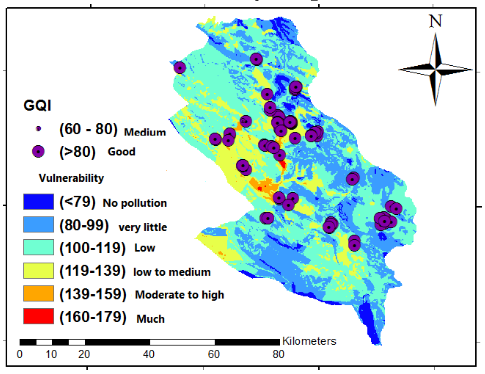

Figure 18. drastic vulnerability map and groundwater quality index based on ISIRI standards

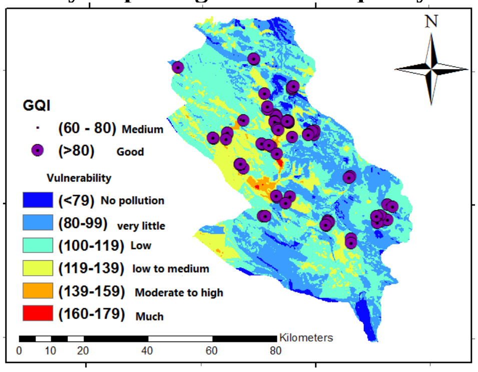

Figure 19. drastic vulnerability map and groundwater quality index based on WHO standards

4. Conclusion

In recent years, the increase in water consumption and the increasing and costly limitations of the development of surface water resources have led to double pressures on the country's underground water resources. Sustainable access to safe drinking water is necessary and necessary for the well-being and health of human life. Therefore, protection of groundwater quality is an important challenge.

By examining the model used in this aquifer, it can be concluded that the use of more parameters has a great effect on the accuracy of the results. Although this point is not a reason to reject or accept other models; Because many of the models with less parameters can be in the levels and larger scales with fewer parameters provide acceptable results. What comes from the results of this study is that the model Dractic has more acceptable accuracy. The results of the study by Ghanbarian and Ahmadi Nadushan under the title of assessing the vulnerability of the Lordegan Plain aquifer using DRASTIC, AVI, and GODS models confirm this [34]. The current study and its results, because it shows the vulnerability of groundwater to pollution in a complete and visual way, has provided a very valuable tool for officials and managers to make the necessary decisions to improve land use and management of aquifers such as the plain. Adopt management practices in the use of agricultural water and agricultural fertilizers, urban sewage, land use change, etc. According to table (12), the studied area is in the range of no pollution to high pollution in terms of pollution classification. Vulnerable classes in order: low pollution 42.71%, very low 33.53%, low to medium 17.83%, no pollution 4.07%, medium to high 1.57% and high 0.29%. includes In these areas, the natural conditions of the region, such as low slope, precipitation of more than 700 mm, high nutrition, sand and lime in the aquifer environment and high hydraulic conductivity, have created a high potential for increasing the level of vulnerability, which is necessary to prevent pollution. Groundwater, more care and control should be considered. In general, it can be concluded that based on the results of the Drastic model, the western and central regions of the study area have the highest potential of being vulnerable to pollution.

In this research, Drastic model was used to evaluate pollution, but there are other models to evaluate vulnerability. Therefore, it is necessary to try other models to assess the vulnerability so that the model is selected according to the local hydrogeological conditions of the region.

Author contributions

The entire research process was done by myself as the responsible author.

Appreciation

The author is grateful to Chaharmahal and Bakhtiari regional water organization for providing raw data related to the studied aquifers.

Conflict of interest

No financial assistance or fees were received from any person or organization for conducting this research.References

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