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Aquifer vulnerability assessment in a semi-arid zone of Iran

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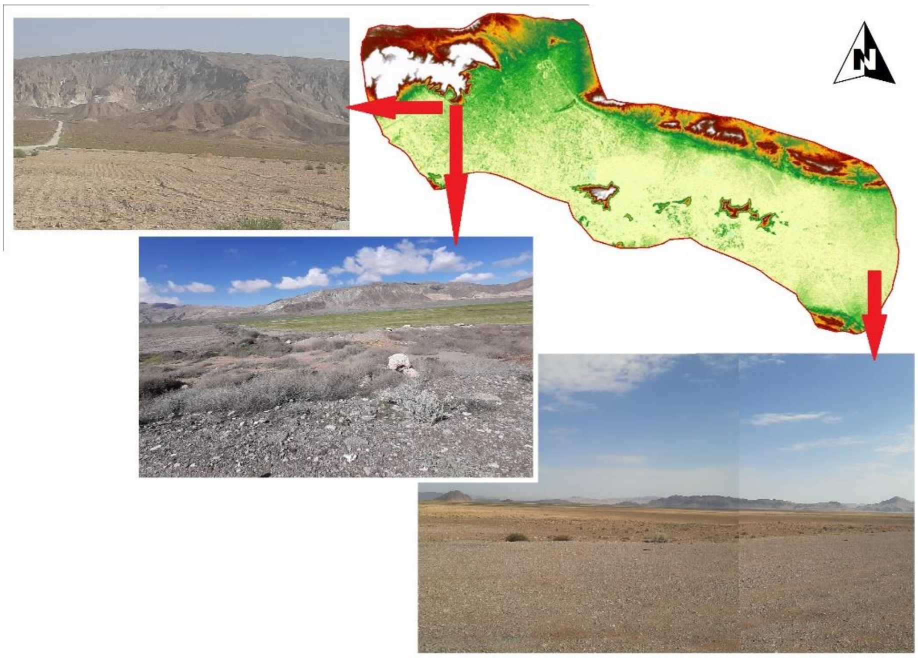
GRAPHICAL ABSTRACT



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ABSTRACT

The importance of water shortage in arid and semi-arid regions is more evident due to the limitation of water resources, and the preparation of water resources is necessary to protect and reduce the vulnerability of these resources. Therefore, in this study, considering the vulnerability of water and soil resources in arid and semi-arid regions and the geographical structure of Zagros inland basins, the Izadkhast plain from the south of Fars province was selected to investigate the vulnerability of water resources. For this purpose, six parameters of water depth, net feed, aquifer environment, soil texture, topography, and hydraulic conductivity of the aquifer were analyzed using the DRASTIC model. The results showed that almost 50% of the plains were in the high vulnerability class, and 28% were in the very high vulnerability class. In the east and center of the plain, places with high vulnerability to pollutants and contaminated water were found. The effect of the formations in the east of the basin can be seen because, at the outlet of the rivers in the east of the basin, the amount of sulfate has increased dramatically, which indicates the presence of evaporate formations with gypsum. In the center of the basin, the heavy texture of the soil, the low slope, and the accumulation of most of the 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 has high efficiency in evaluating vulnerabilities similar to this research.

1. Introduction

Although the total amount of water in the world is constant, its inappropriate distribution in the world and, most importantly, the lack of fresh and healthy water in different parts of the world has caused many concerns that the importance of this issue is more pronounced in arid and semi-arid regions. Considering the importance of groundwater aquifers in arid and semi-arid regions to increase the population and consequently increase consumption and utilization of these resources, these reservoirs have been seriously threatened (Azizi and Nejatian, 2021). This has caused the salinization of underground water reserves and the loss of the balance between salt and fresh water, and the advance of salt water to the fresh underground aquifers. Therefore, due to the limitation of surface and groundwater resources, planning water resources for conservation seems necessary to reduce the vulnerability of these resources. The conservation and maintenance of groundwater

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quality in the broad area include two sets of hydrological studies and water resources management policies, which can generally be investigated and described through the vulnerability component. Vulnerability is conceptually divided into two intrinsic and specific classifications, which is an inherent vulnerability to the concept of aquifer sensitivity to natural factors. However, particular vulnerability investigates the inherent vulnerability along with the possibility of groundwater exposure to pollutant penetration (Nohegar and Riahi, 2014).

In this regard, remote sensing techniques and GIS are powerful tools for investigating and predicting environmental changes in a reliable, repetitive, fast, and cost-effective way with decision-making strategies (Amiri *et al*., 2014). So far, different methods have been proposed to assess the vulnerability of aquifers, which can be divided into three general categories. These three categories are the subjective rating method, statistical and process-based method, and Hybrid Method. Statistical and analytical methods usually require the preparation of mathematical models and are more complicated than the ranking methods (Niknam *et al*., 2007). One of the most critical ranking methods (Eftekhari and Akbari, 2020) is the DRASTIC method. One of the main advantages of the Plastic model is the assessment of vulnerability using a large number of information layers. Because it is believed that, in this case, the effects of errors and uncertainties in a single parameter are limited in the final output (Maroufi *et al*., 2012).

This method was first designed by the Environmental Protection Agency of the United States of America in cooperation with the National Groundwater Association to assess the potential of groundwater pollution caused by emission pollutants (Aller *et al*., 1987) and quickly in different parts of the world, such as China (Bai, Wang, and Meng, 2012), Portugal (Pacheco and Sanches Fernandes, 2013), the United States of America (Agyemang, 2017), Algeria (Guettaia *et al*., 2017), Indonesia (Machdar *et al*., 2018), Pakistan (Maqsoom *et al*., 2020) and Tanzania (Mkumbo *et al*., 2022) were used. The power of this model to determine the level of vulnerability of underground water resources was confirmed. Therefore, in this research, considering the vulnerability of water and soil resources in arid and semi-arid regions and the geographical structure of the internal basins of Zagros, Izadkhasht plain from the south of Fars province was selected to investigate the vulnerability of its water resources. Due to the closure of the studied plain and the transfer of inlet waters to the center of the basin and its evaporation, finally, the soil salinity structure in the basin is revealed. On the other hand, the high salinity of underground water and the drying up of a significant number of wells in the region in recent years, as well as the lack of proper and principled use of surface water resources, cause salinity and soil degradation and desertification of basin lands. Therefore, in this research, the main goal is to assess the vulnerability of underground water resources using the DRASTIC model to manage water resources in the basin.

2. Materials and methods

2.1. Study area

The Izadkhast Plain is one of the closed basins of the Mand River basin located in Fars province (Fig. 1). The area of this basin is 612.3 km^2. The maximum height in the basin is 1778, and the minimum height is 1035 m. This basin has an average annual precipitation of 222.1 mm, an average annual temperature of 19.5 degrees, and an average annual evaporation from the basin of 2955.9 mm.

There is no permanent river in this basin, and all flows are temporary and seasonal. All surface flows of the region are convergent, flowing from the margin to the center of the plain and eventually accumulating in the center and west of the plain. In the center of the plain, the stagnant water after evaporation shows the salty and unusable land. Groundwater aquifers are also the most critical water resources in this basin. Digging deep and semi-deep wells and harvesting from alluvial aquifers on the plain surface located in the study areas are the most critical methods of harvesting in this region. According to statistics and data from 2009, about 30 million m^3 of groundwater resources have been harvested, which has been carried out by 166 deep and semi-deep wells, of which 43 wells have been dried and abandoned from 2001 to 2009. However, according to the statistics of 2018, the drilling of wells in this basin has increased and reached 302 wells in the said year, of which 145 are dry and abandoned, and the annual discharge is reported to be about 21 million cubic meters. Underground resources in this area have shown a downward trend in the past years (Plan and budget organization, 2014).

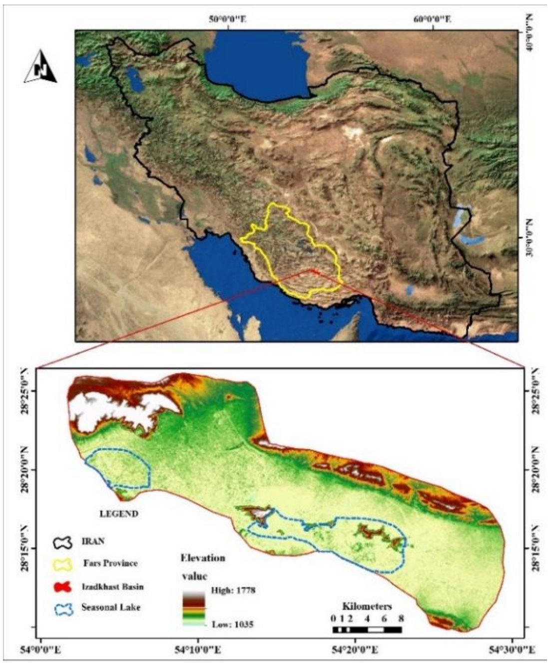


Fig. 1. The study area.

2.2. Data and research methods

In this study, the DRASTIC method was used to assess the vulnerability of groundwater resources in the Izadkhast plain. This method is based on seven parameters of water depth, net nutrition, aquifer environment, soil texture, topography, the influence of unsaturated zone, and hydraulic conductivity of the aquifer. In this method, each parameter is assigned a rate and a weight based on the importance of the parameter, which varies between 1 and 10 in each parameter, and the weight of each parameter varies between 1 and 5 according to its importance, which is calculated as Eq. 1.

$$DI= D_rD_w+ R_rR_w+ A_rA_w+ S_rS_w+ T_rT_w+ I_rI_w+ C_rC_w \quad (1)$$

Where, DI is the DRASTIC index, D, R, A, S, T, I, and C are the seven parameters, r is the value rate (rank), and w is the weight assigned to each parameter (Khosravi *et al*., 2013). Therefore, due to a lack of information, the unsaturated zone parameter of six parameters was used to implement the model of water depth, pure nutrition, aquifer environment, soil texture, topography, and hydraulic conductivity of the aquifer from observational water level maps (Fars Regional Water Authority), precipitation, geology, soil, slope, and water supply (Fig. 2) (Tables 1 to 6).

Table 1. Groundwater depth ranking, m.

Range	0.5-1	1.4-5.6	4.9-6.1	1.2-9.15	2.8-15.22	8.4-22.30	>30.4
Rank	10	9	7	5	3	2	1

Table 2. Topography (slope, %).

Range	0-2	2-6	6-12	12-18	>18
Rank	10	9	5	3	1

Table 3. Feed, mm.

Range	0-2	2-6	6-12	12-18	>18
Rank	10	9	5	3	1

Table 4. Hydraulic conductivity, m/day.

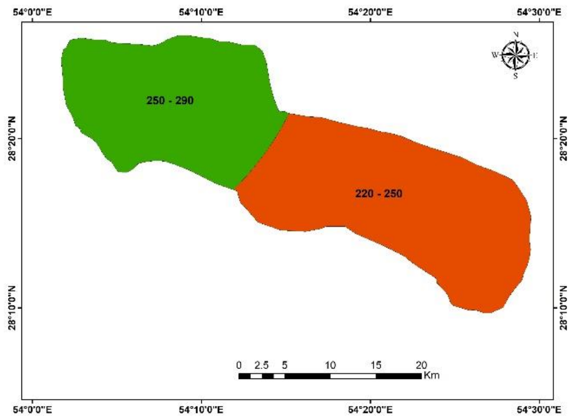
Range	0.4-4.1	1.3-4.12	3.7-12.28	7-28.41	41-82	>82
Rank	1	2	4	6	8	10

Table 5. Aquifer environment.

Formation type	Mass Shale	Metamorphic	Weathered Metamorphic	Alluvial	Sandstone and limestone	Shale and Limestone	Sandstone mass	Sand	Basalt	Karst limestone
Rank	2	3	4	5	6	6	6	8	9	10

Table 6. Soil environment.

The type of soil layer	Thin or Lack	Gravel	Sand	Peat	Cracked Clay	Loamy Sand	Loam	Loamy Silt	Loamy Clay	Muck	Lack of Cracked Clay
Rank	10	10	9	8	7	6	5	4	3	2	1



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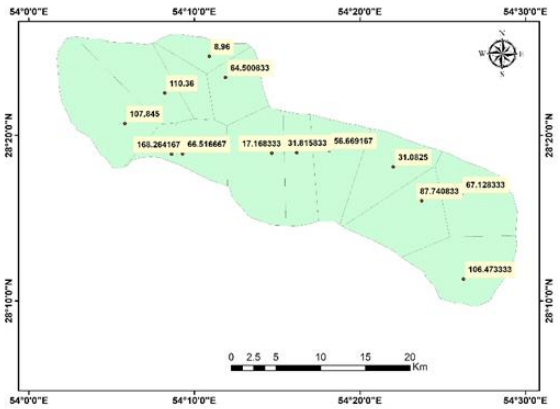

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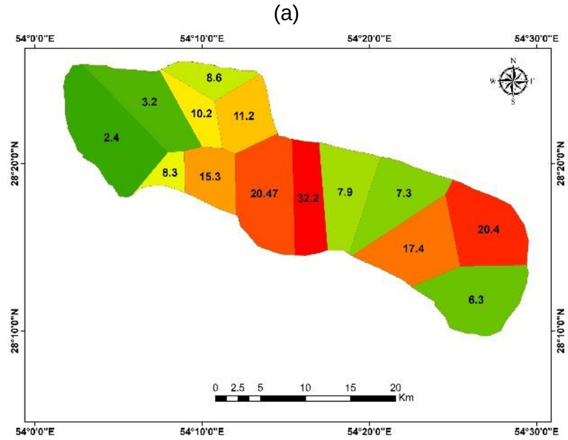

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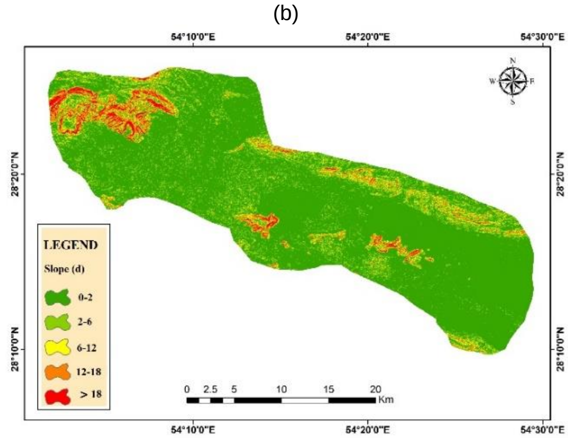

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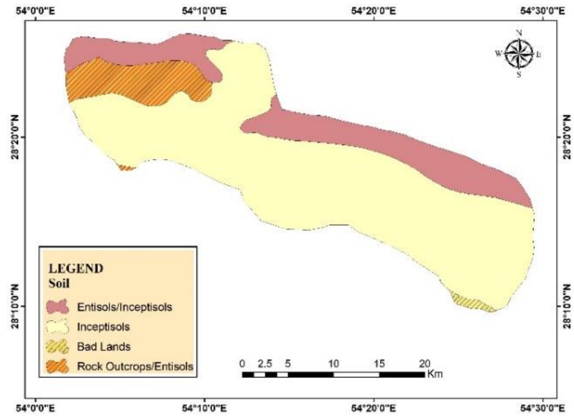
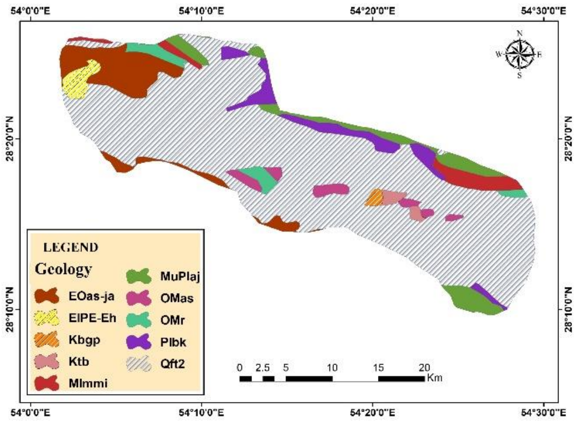


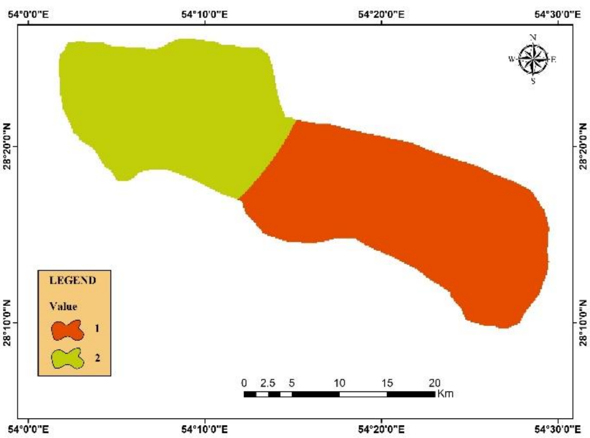


(e) (f)

Fig. 2. DRASTIC parameters map (a) Rainfall (mm), (b) Level of observation wells, m, (c) Hydraulic conductivity, m/day, (d) The Slope of area, %, (e) Pedology, and (f) Geology.

3. Results and discussions

To evaluate the vulnerability of underground water resources using ranked maps (Fig. 3), the map of the vulnerability of underground water resources in the Izadkhast Plain was extracted using the DRASTIC index (Fig. 4). The results of this research showed that about 250 km^2 of the Izadkhast Plain are in the high vulnerability class, which covers about 45 % of the plain. Also, after the high class, the very high class, with an area of about 159 km^2, is in the next rank (Fig. 4 and Table 7). According to the DRASTIC Index, almost 50% of the plains were in the high vulnerability class, and 28% were in the very high vulnerability class. There were places in the east and center of the plain that were very vulnerable to pollutants and contaminated water. For accuracy, by placing water quality parameters zoning maps (Ansari, Jabbari, and Sargordi, 2021a) on the vulnerability map, the above map shows precisely the places where groundwater resources have lower quality, such as research conducted on groundwater resources of Khatun Abad plain in Kerman Province and to verify nitrate concentration points on the DRASTIC index map (Nakhaei, Amiri, and Rahimi-Shahrebabaki, 2013).



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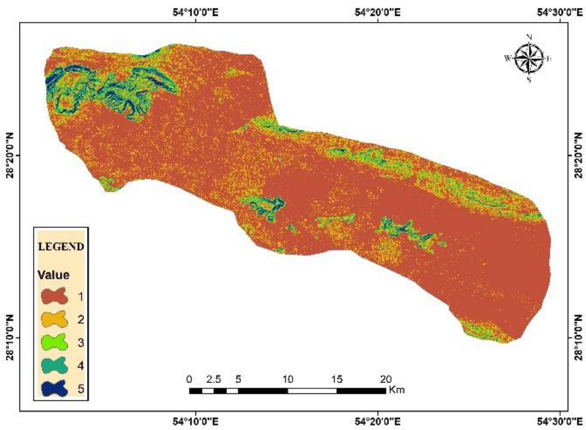

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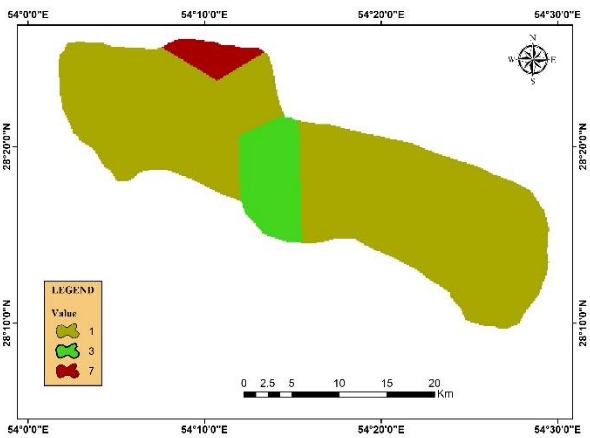

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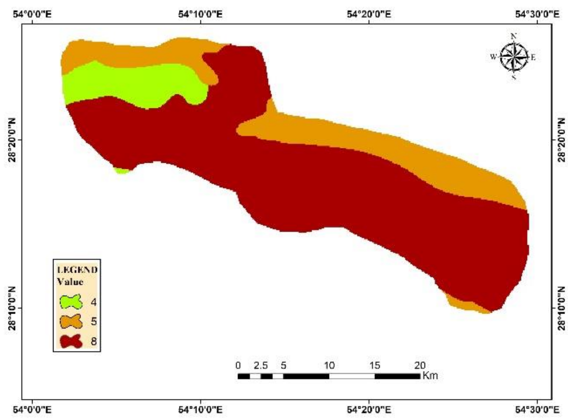

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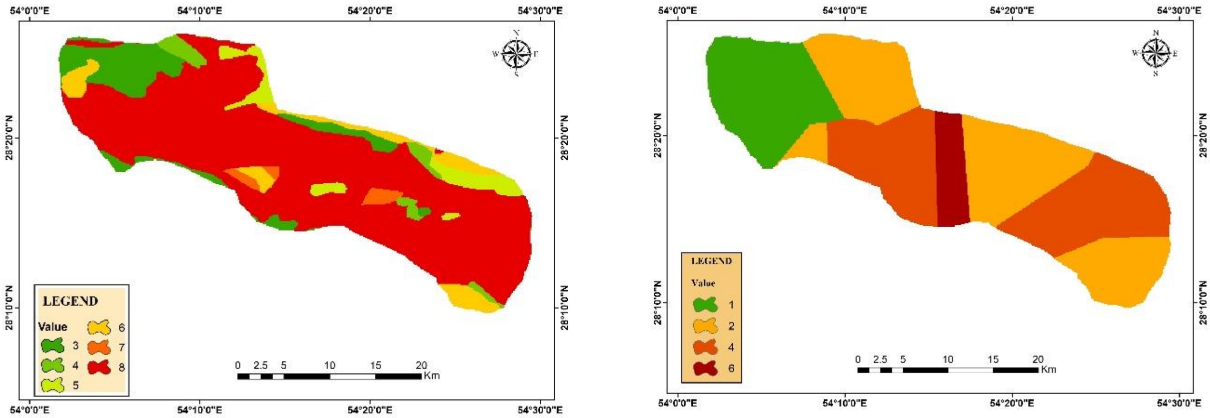

(e) (f)

Fig. 3. Weighting of DRASTIC index parameters, (a) Feeds, (b) Slope, (c) Ground water depth, (d) Soil environment, (e) Aquifer environment, and (f) Hydraulic conductivity.

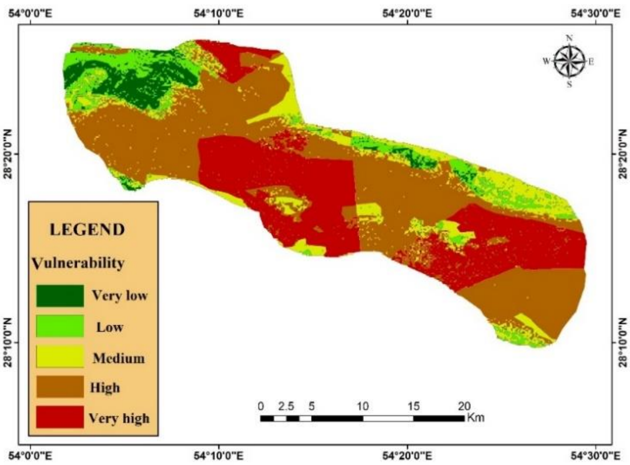

Fig. 4. DRASTIC index of the Izadkhast plain.

Table 7. Area and percentage of the DRASTIC index classes in the Izadkhast plain

DRASTIC index vulnerability	Area	%
Very low	29.57	5.29
Low	45.43	8.13
Medium	74.25	13.30
High	250.56	44.87
Very high	158.65	28.41
Sum	558.46	100

On the other hand, the accuracy of the DRASTIC model in assessing the vulnerability of groundwater resources in the research of Guettaia *et al.* (2017) in Algeria and Khosravi *et al*. (2012) in Dehgolan plain of Kurdistan province has also been confirmed. The geomorphological analysis of the model results shows that large parts of the region are in flat lands, and the slope is less than 5 degrees. Due to the particular topography and closure of the basin, streams flow from around the basin to the center of the plain. These flows also bring many salts to the plain from the east due to the presence of gypsum formations and from the west because of the presence of salt dome. This has caused the salting of soil with different degrees in the plain (Ansari, Jabbari, and Sargordi, 2023), which causes vulnerability of basin water resources. Including in the place of accumulation of superficial parts in the center of the plain in the rainy season, which forms a swamp, causes a lot of salinity in this part. In addition, poor drainage condition leads to the high salinity of this part. Also, due to the entry of rivers in the east of the basin, soils in some parts have a gypsum concentration floor. Therefore, in the center of the basin, due to the heavy texture of the soil, the low slope of this point, and the accumulation of most of the water that is transferred to this part by several branches and leaves a lot of salts in it, its vulnerability has increased.

In the lands above the seasonal lake, that is, at the beginning of the flat lands and on the border of the hilly and mountainous lands with the flat plain lands that have a slope of between one and three percent, there are slope and sedimentary plains, which due to the texture and appropriate soil depth are mainly dedicated to hydroponic farming. In this part, due to the arrival of rivers from mountain to plain, which carry salt and gypsum salts and human activities are considered vulnerable areas.

Also, in the east of the plain, due to the low slope, feeding rate, and soil type, the DRASTIC model has correctly identified high vulnerability. In this section, when two rivers leave the mountains east of the basin and flow towards the center of the plain, a lot of sediments are washed from the heights of the basin and brought to the plain. The evaporation of accumulated water in this part also stains the evaporative sediments with lemons, which changes the texture and quality of the soil (Ansari, Jabbari, and Sargordi, 2021b).

4. Conclusions

Groundwater aquifers in arid and semi-arid regions have been seriously threatened due to the increase in population and subsequently increased consumption and utilization of these resources. To manage these reservoirs, it seems necessary to investigate their vulnerability. A DRASTIC model is a suitable method for this evaluation, in which critical influential factors are extracted. This model has the advantage of revealing the areas covered by different damages according to the geomorphological data and allowing fundamental analyzes to be performed on them. This analysis of the Izadkhasht plain shows that parts of the plain are exposed to high vulnerability, that the washing of saline formations and their emptying in the lowest places and especially their evaporation leaves evaporative formations such as gypsum, which increases the amount of sulfate in these places. The production of soils with heavy texture, low slope of these points, and the persistence of accumulation of inlet waters by branches with solutes and evaporation create a cycle that increases salinity and gradually increases vulnerability to desertification risk.

Author Contributions

Maryam Ansari: Collected the data; Contributed data or analysis tools; Wrote the paper
Iraj Jabbari: Conceived and designed the analysis; Performed the analysis; Other contribution: Edit, control, revised and guidance

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Conflict of Interest

The authors have no conflict of interest.

Data Availability Statement

Data will be available on request.

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