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Groundwater Vulnerability of Halabja-Khurmal Sub-Basin Using Modified DRASTIC Method

Lanja F. Rauf · Salahalddin S. Ali · Nadhir Al-Ansari

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Abstract Evolving groundwater vulnerability from DRASTIC to modified DRASTIC methods helps choose the most accurate areas that are most delicate toward pollution. This study aims to modify DRASTIC with land use and water quality index for groundwater vulnerability assessment in the Halabja-Khurmal sub-basin, NE/Iraq. The Halabja-Khurmal sub-basin groundwater vulnerability index is calculated from nine hydrogeological parameters by the overlay weighting method. As a result, 1.3% of the total area has a very high vulnerability value and 46.1% with high vulnerability. The regions with high groundwater vulnerability have a high-water table and groundwater recharge. Nitrate concentration was used to validate the result, and the Pearson correlation and recession analysis between the modified DRASTIC index and nitrate concentration depicted a strong relation with 0.76 and 0.7, respectively.

L. F. Rauf
Department of Geology, College of Science, University of Sulaimani, 460013 Sulaymaniyah, Iraq
e-mail: lanja.farooq@komar.edu.iq

S. S. Ali
College of Engineering, Komar University of Science and Technology, 46001 Sulaymaniyah, Kurdistan region, Iraq
e-mail: salah.saeed@komar.edu.iq

N. Al-Ansari (✉)
Lulea University of Technology, 971 87, Lulea, Sweden
e-mail: nadhir.alansari@ltu.se

Keywords Groundwater vulnerability · Modified DRASTIC · Land use · Nitrate pollution · Water quality index

1 Introduction

In later decades, due to the rise in anthropogenic activities, the tendency of groundwater toward pollution increased as well; consequently, groundwater vulnerability became a concept globally for understanding and better managing underground water resources.

Margat introduced the groundwater vulnerability concept in 1968 and more widely used in the 1980s like DRASTIC by Aller et al. (1987), GOT by Foster (1987), AVI by Van Stempvoort et al. (1993), SINTACS by Civita (1994), and many other modifications to them based on adding or subtracting parameters. The National Research Council (1993) and Hirata and Bertolo (2002) proposed multiple descriptions for this concept. The concept can be illustrated as the overlying layer of the saturated zone protecting the aquifer from contaminating the saturated zone. Although this concept cannot be measured directly, it can be assessed through the intrinsic property of natural aquifer systems and human activities such as DRASTIC and DRASTIC-like techniques.

The sensitivity of the unsaturated zone in the studied area toward the contamination can be determined by analyzing the hydraulic approachability and contaminant depletion, factors that affect climate, more specifically precipitation, which is responsible for water recharge and depth to water level. The other factors are the thickness of the soil, aquifer properties, slope, water quality, and human activities using the land for different purposes.

DRASTIC is a well-known method developed for the US Environmental Protection Agency (EPA) by Aller et al. (1987). Several studies used DRASTIC to determine the groundwater vulnerability areas such as (Abdeslam et al., 2017; Al-Adamat et al., 2003; Al-Hayali et al., 2021; Aller et al., 1987; Al-Madhlom et al., 2016; Al-Rawabdeh et al., 2013; Baalousha, 2006; Cameron & Peloso, 2001; Hamamin, 2011; Jamrah et al., 2008; Kumar et al., 2014; Melloul & Collin, 1998; Merchant, 1994; Sener et al., 2009; Zghibi et al., 2016). In addition, other studies focused on the estimation of groundwater vulnerability by using a DRASTIC-like technique to improve the vulnerability region execution (Abdullah et al., 2015, 2016, 2020; Al-Qurnawi, 2014; Al-Rawabdeh et al., 2014; Fritch et al., 2000; Hamamin et al., 2016; Manhi, 2012; Secunda et al., 1998; Zhang et al., 2021).

Pressure on the water resources inclines worldwide. The study area is one of the places that will face groundwater quality issues due to the development within the area and water scarcity, a reason that adequate protection and management of the water resources are vital to guarantee the quality of drinking water (WWF, 2019). A groundwater vulnerability map can assist in this criterion by selecting the delicate areas for pollution. However, some studies on the area choose a more extensive scale but a more miniature depiction of minor scales, such as the Halabja-Khurmal sub-basin in the Halabja governorate. In the present study, a smaller-scale sub-basin has chosen to define vulnerability maps with nine parameters to achieve accurate results using the DRASTIC-like technique. Land use is one of the essential parameters in the area of interest as it passively affects underground water quality, especially on agricultural land. Human activities on land affect the quality of underground water; therefore, groundwater quality plays an essential role in structuring the dedication of an area toward pollution. Water quality index is a fine indicator for giving a close sight of the groundwater condition. By modifying and adding a land use layer and water quality index to the DRASTIC method, the performance of the technique will be better than the classic version (Shirazi et al., 2012; Secunda et al., 1998; Singh et al., 2015; Roohollah et al., 2018, Zhang et al., 2021). Therefore, this study is about creating groundwater vulnerability maps using by DRASTIC-like method to evaluate the area and find the vulnerable spots of underground water in the Halabja-Khurmal sub-basin.

2 Study Area

Geographically, the area of interest is located within the Halabja governorate, which split away from the Sulaimani governorate in 2014 to become a fourth governorate in the Kurdistan region of Iraq. It is located about 240 km northeast of Baghdad, 14 km from the Iranian border, and 78 km southeast of Sulaimani city, with a population of about 118,924 in 2021, based on data from Sulaimani Statistical Directorate. The capital is “Halabja city” and has three districts: Sirwan, Khurmal, and Byara. It is surrounded by Hawraman, Shnrwe, and Balambo Mountains. Halabja-Khurmal sub-basin is located in the northeastern part of Iraq (Fig. 1); it covers an area of 488.62 km^2 at the coordinates of 571,545–606,290 east and 3,884,112–3,916,597 north in the Universal Transverse Mercator (UTM) and lies in Zone 38 N with the elevation ranging between 455and2609 m. The climate of the studied area is characterized by rainy cold winter and dry hot summer with an average annual air temperature ranging between 3.3 and 43.4 °C, with total annual precipitation of 622.6 mm for the period of 20 years (2001–2021).

Geologically, the studied area is positioned within Western Zagros Fold-Thrust Belt, and structurally, it is situated within high folded zone, imbricated, and thrust zones (Buday & Jassim, 1987; Jassim et al., 2006). The age of the rock formations ranges from Triassic to Quaternary (Fig. 2).

Hydrogeologically, the Halabja-Khurmal subbasin composes of several aquifer types based on the geological setup of the area (Ali, 2007):

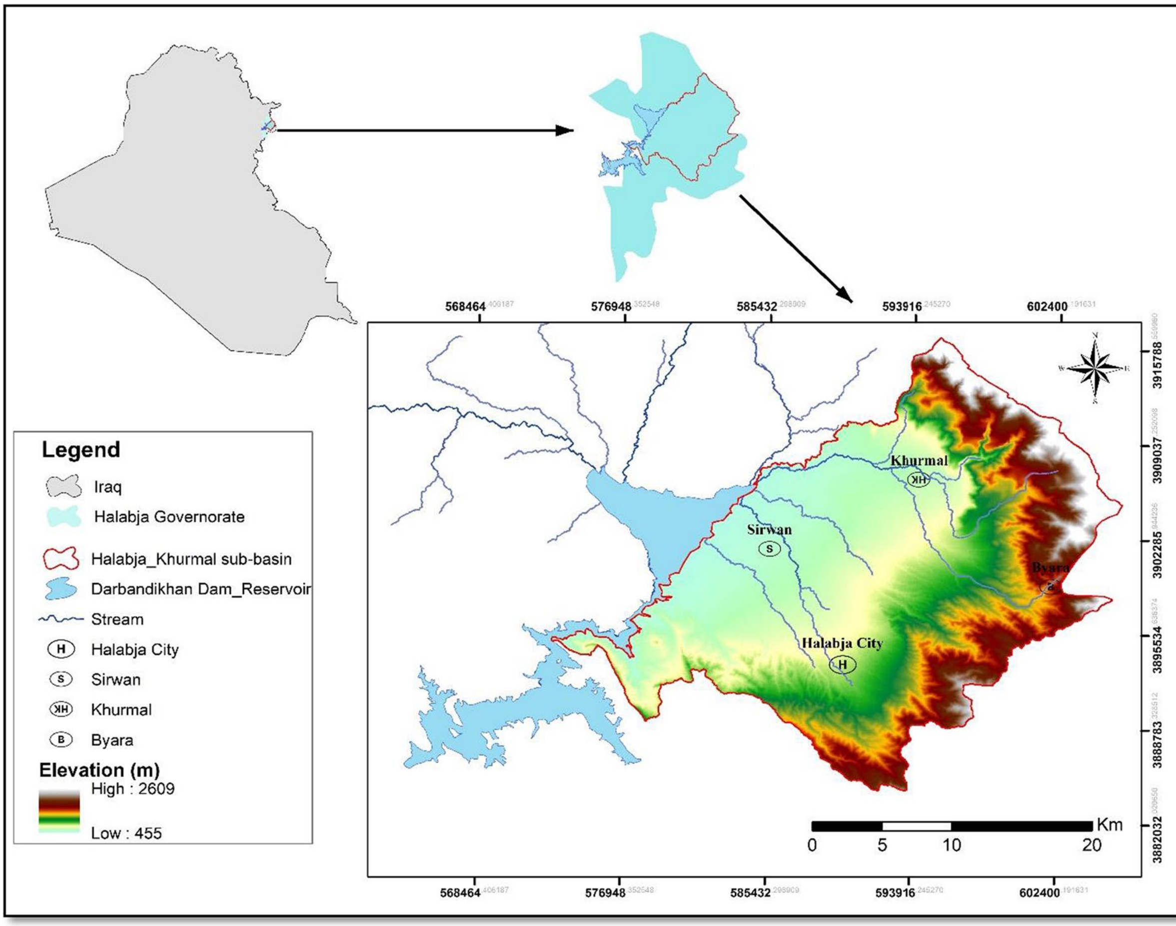

Fig. 1 Location map of Halabja-Khurmal sub-basin

Triassic and Jurassic karstic aquifers in the north and northeastern part, Eocene karstic-fissured aquifer in the southwestern, Cretaceous karstic-fissured aquifer in the southeastern, Cretaceous fissured aquifer in the east, in the southwestern part there are aquitard and aquiclude aquifers, and the major aquifer in the sub-basin is alluvium intergranular aquifer which occupies around 62% of the total area which characterizes by a good yielding aquifer. Groundwater is shallow in the center and toward Darbandikhan lake from the western side of the sub-basin. On the other hand, the high elevated areas from the north, northeastern, east, and southeastern parts.

have deep groundwater levels. Groundwater flows in the sub-basin toward Darbandikhan lake (Rauf, 2014).

3 Materials and Methods

Groundwater vulnerability maps are designed to show the most significant potential groundwater contamination areas based on the hydrogeologic and anthropogenic factors. The GIS database for the modified DRASTIC model developed using nine input parameters of multiple maps needed for creating this model was prepared and built using available hydrogeological data with the help of ArcGIS 10.7.1.

3.1 Data Source

Many field surveys in the studied sub-basin were done to overview the areas: geology, soil,

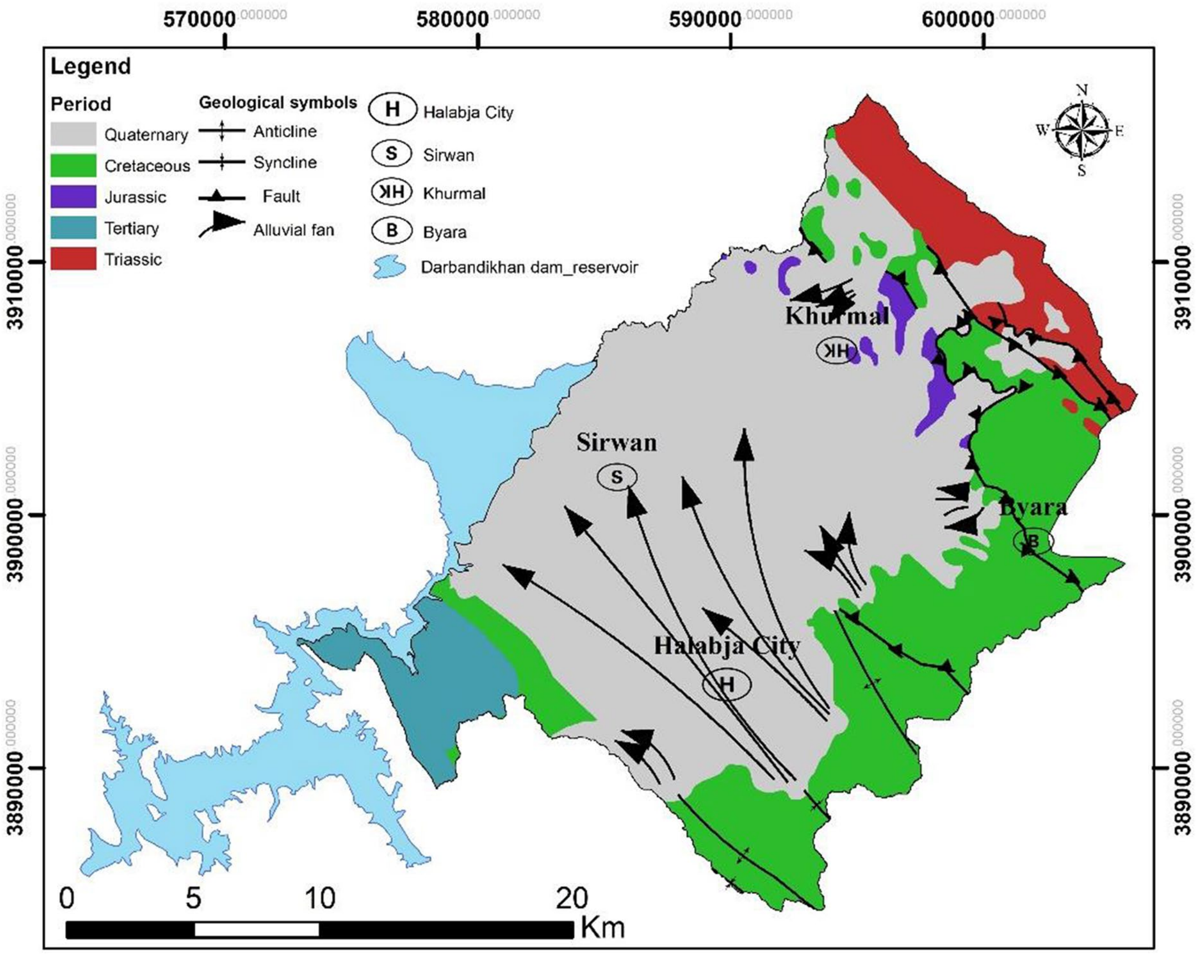

Fig. 2 Geological formation periods modified after (Sissakian & Fouad, 2015)

lithology, and hydrogeology. Then, an appropriate location and the number of boreholes and springs for groundwater samples were selected. The samples from the boreholes and springs were collected in clean, sterilized 500-ml bottles. The collected water samples were then refrigerated at 4 °C before being analyzed. The physio-chemical parameters of the water samples that were analyzed are as follows:

The EC, pH, TDS, turbidity, and temperature were measured in situ. The titration method determined chloride, alkalinity as HCO_3^-, calcium, and magnesium. Nitrate and sulfate were analyzed using a spectrophotometer. A flame photometer was used to analyze sodium and potassium. Many data from various sources were used for achieving vulnerability maps in the Table 1 and Flowchart 1.

3.2 Construction of Modified DRASTIC Index (MDI)

The modified DRASTIC method was used to generate a groundwater vulnerability map model. GIS software is a powerful function used to construct the groundwater's vulnerability map. Based on the groundwater vulnerability assessment model, the DRASTIC model is joined with two specific parameters to develop the comprehensive groundwater vulnerability index by overlaying the nine impact factor score of the main hydrogeological parameters

Table 1 Data used as the source for creating the modified DRASTIC model

Data	Used to produce	Data sources
Borehole	D map	Fieldwork and *SGD data
Precipitation and evaporation	R map	Meteorological **stations
Geology and borehole	A map	Iraq Geology Survey and SGD
Soil map	S map	FAO, 2001, Berding, 2003, and Iraq Geology Survey
Digital elevation model	T map	USGS Earth Explorer
Lithology	I map	SGD data
Well pumping test	C map	Fieldwork and SGD data
Satellite image	LU map	USGS/ Earth data NASA
Physio-chemical analysis	WQI map	Fieldwork and groundwater sample analysis

*Sulaimani groundwater directorate (2021). **Halabja, Khurmal, Byara, and Sirwan stations

Flowchart 1 Methodology for creating MDI model

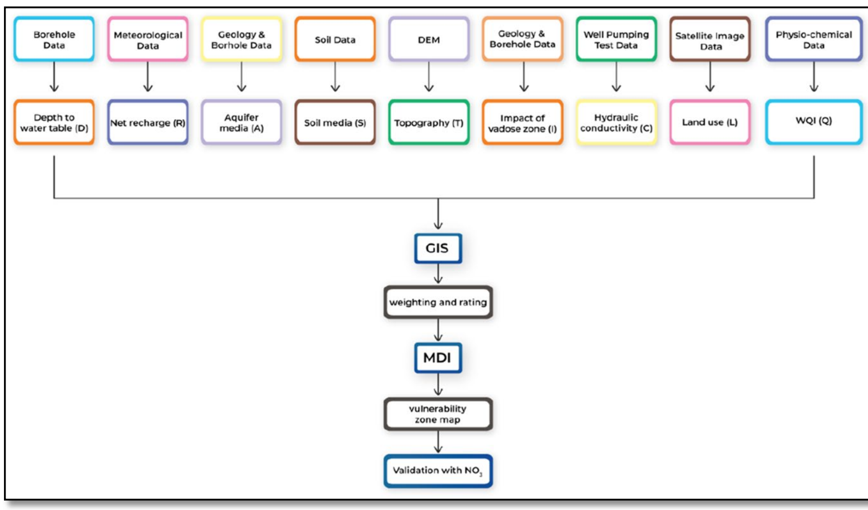

Table 2 Rating and weight scheme of DRASTIC D, R, T, and C parameter maps (Aller et al., 1987)

Depth to water level (m) weight = 5							
Range	0–1.5	1.5–4.5	4.5–9	9–15	15–23	23–30	> 30
Rating	10	9	7	5	3	2	1
Net recharge (mm/year) weight = 4							
Range	0–50	50–100	100–175	175–250	> 250		
Rating	1	3	6	8	9		
Topography (slope %) weight = 1							
Range	0–2	2–6	6–12	12–18	> 18		
Rating	10	9	5	3	1		
Hydraulic conductivity (m/day) weight = 3							
Range	0–4	4–12	12–30	30–40	40–80	> 80	
Rating	1	2	4	6	8	10	

Table 3 Rating and weight scheme of DRASTIC *A*, *S*, and *I* parameter maps (Aller et al., 1987)

Aquifer media		Soil media		Vadose zone	
Weight = 3	Rating	Weight = 2	Rating	Weight = 5	Rating
Massive shale	2	Non-shrinking and non-aggregated clay	1	Silt/clay	1
Metamorphic/igneous	3	Muck	2	Shale	3
Weathered metamorphic/igneous	4	Clay loam	3	Metamorphic/igneous	4
Thin bedded sandstone, limestone, shale	6	Silty loam	4	Limestone	6
Massive sandstone	6	Loam	5	Sandstone	6
massive limestone	8	Sandy loam	6	Bedded limestone, sandstone, shale	6
Sand and gravel	8	Shrinking and/or aggregated clay	7	Sand and gravel with significant silt and clay	6
Basalt	9	Peat	8	Sand and gravel	8
Karst limestone	10	Sand	9	Basalt	9
		Thin or absent gravel	10	Karst limestone	10

with the land use and water quality index. The score value of each index is calculated based upon their contribution related to groundwater contamination by rating (1–10) given to each subclass of the maps of *D* (depth to the water table), *R* (net recharge), *A* (aquifer media), *S* (soil media), *T* (topography), *I* (impact of the vadose zone), *C* (hydraulic conductivity), *L* (land use), and *Q* (water quality index) and weighting (1–5) given to each of nine maps. Tables 2 and 3 show the rating and weighting values of the inherent vulnerability based on (Aller et al., 1987) and Table 4 based on (Chaterjee & Raziuddin, 2002; Secunda et al., 1998; Zhang et al., 2021). Figure 3 shows the layers of each of nine parameters for creating a modified DRASTIC index (MDI) and MDI calculated based on the following equation:

Table 4 Rating and weight scheme of specific vulnerability parameter maps (Chaterjee & Raziuddin, 2002; Secunda et al., 1998; Zhang et al., 2021)

LU		WQI	
Weight = 5	Rating	Weight = 4	Rating
Vegetation and barren land	5	< 25	1
Rivers and lakes	7	26–50	3
Cultivated land	8	51–75	5
Rural and agriculture	8	76–100	7
Rural and industrial	9	> 100	10
Urban and industrial	10		

$$MDI = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w + L_r L_w + Q_r Q_w \quad (1)$$

where *MDI* is the modified DRASTIC index and the subscripts *r*, and *w* represents rating and weighting, respectively, assigned for each parameter.

3.3 Correlation Analysis of the Modified DRASTIC Model with Nitrate Concentration

Any methods without validation can result in faulty conclusions and subjective vulnerability assessment. Therefore, to keep away from subjectivity, parameter comparison testing and mapping of validation alternatives are necessary (Ramos-Leal & Rodriguez, 2003).

To perform a validation test and determine the vulnerability assessment using modified DRASTIC nitrate concentration in groundwater was selected as a pollution indicator in the studied area to verify the result of groundwater vulnerability (Arauzo, 2017).

Table 5 Detailed information on MDI

Vulnerability index (Aller et. al, 1987)	Range	Area (%)	Area (km^2)
Low	100–125	25.8	126.1
Moderate	125–150	26.8	130.9
High	150–200	46.1	225.3
Very high	> 200	1.3	6.3

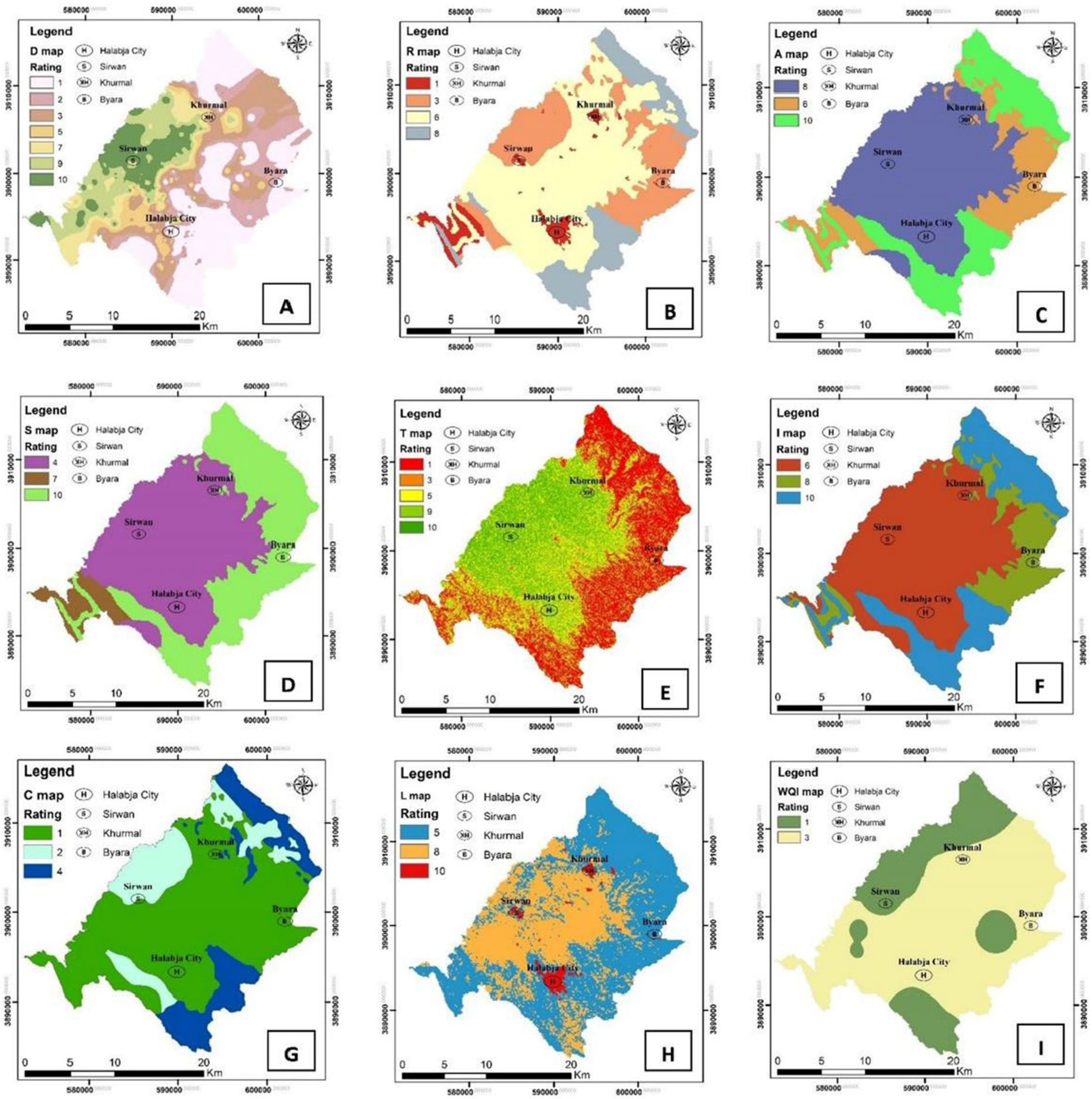

Fig. 3 Input maps for MDI model: **A** depth to water table, **B** net recharge, **C** aquifer media, **D** soil media, **E** topography, **F** impact of vadose zone, **G** hydraulic conductivity, **H** land use, and **I** WQI

Therefore, nitrate data collected from 50 groundwater samples in the Halabja-Khurmal sub-basin (Fig. 4) for two seasons, dry (end of September 2021) and wet (end of May 2022), were used to determine and confirm the significant relationship between them.

To illustrate this validation test correlation value between nitrate, the modified DRASTIC index is calculated through the Pearson correlation coefficient (R). R was determined through the following equation:

$$R = \frac{n(\sum pq) - (\sum p)(\sum q)}{\sqrt{n\sum p^2 - (\sum p)^2}\sqrt{n\sum q^2 - (\sum q)^2}} \quad (2)$$

where R is the Pearson correlation coefficient, n is the data points, and p and q are the nitrate and MDI values, respectively.

4 Results and Discussion

4.1 Groundwater Vulnerability Model

The studied area was classified into four classes based on Aller et al. (1987): low 25.8%, medium 26.8%, high 46.1%, and very high 1.3% of the total percentage of the area (Table 5). Based on the final result depicted in Fig. 5, the total area of (225.3 km^2) with high vulnerability is in the mountainous areas, reflecting the lithology and high hydraulic conductivity of the area, as well as most western and central parts of recent deposits due to the shallow water table, the lithology, and the land use. Medium vulnerable area covers (130.9 km^2) the center and far southwestern toward Darbandikhan dam primarily due to topography and land use. The area of (126.1 km^2) has a low vulnerability in eastern, southwestern, and northward parts of the sub-basin representing a deep-water table and low hydraulic conductivity compared with other classes. On the other hand, 6.3 km^2 represents a very high index, primarily in southwestern and scattered in the sub-basin relatively due to land use, lithology, and recharge of the places.

4.2 Correlation Analysis Result

The results of the correlation analysis depict a significant linear relationship between modified DRASTIC models and the nitrate concentration as R values of

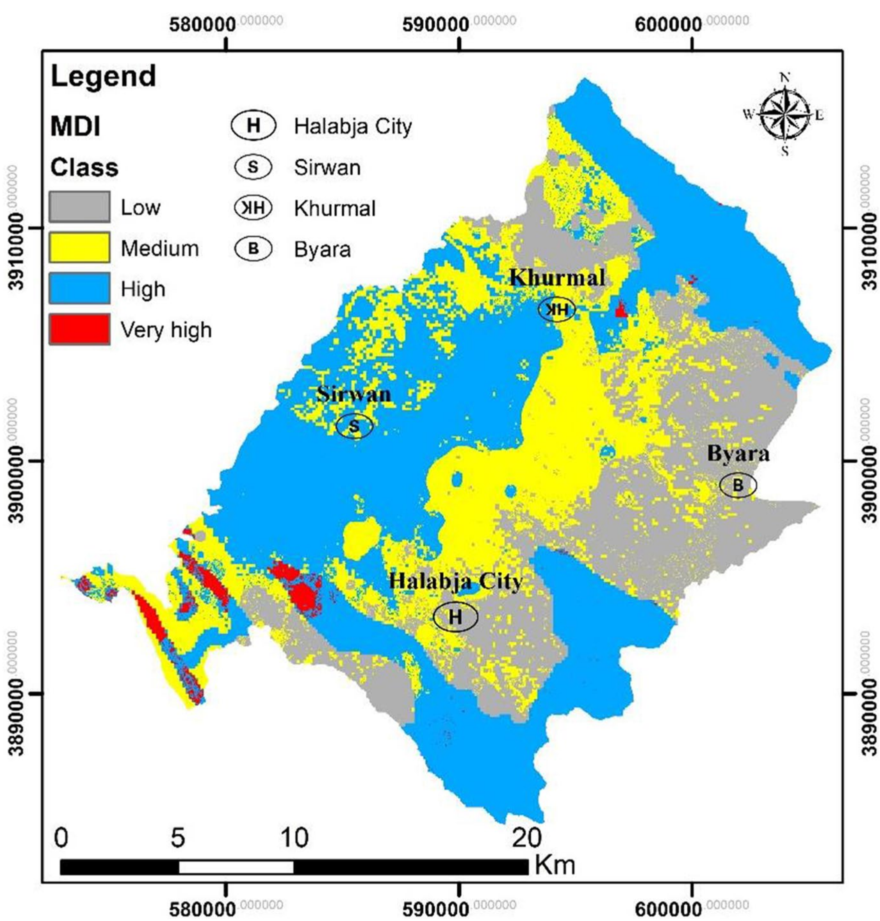

Fig. 4 Location of nitrate sampling

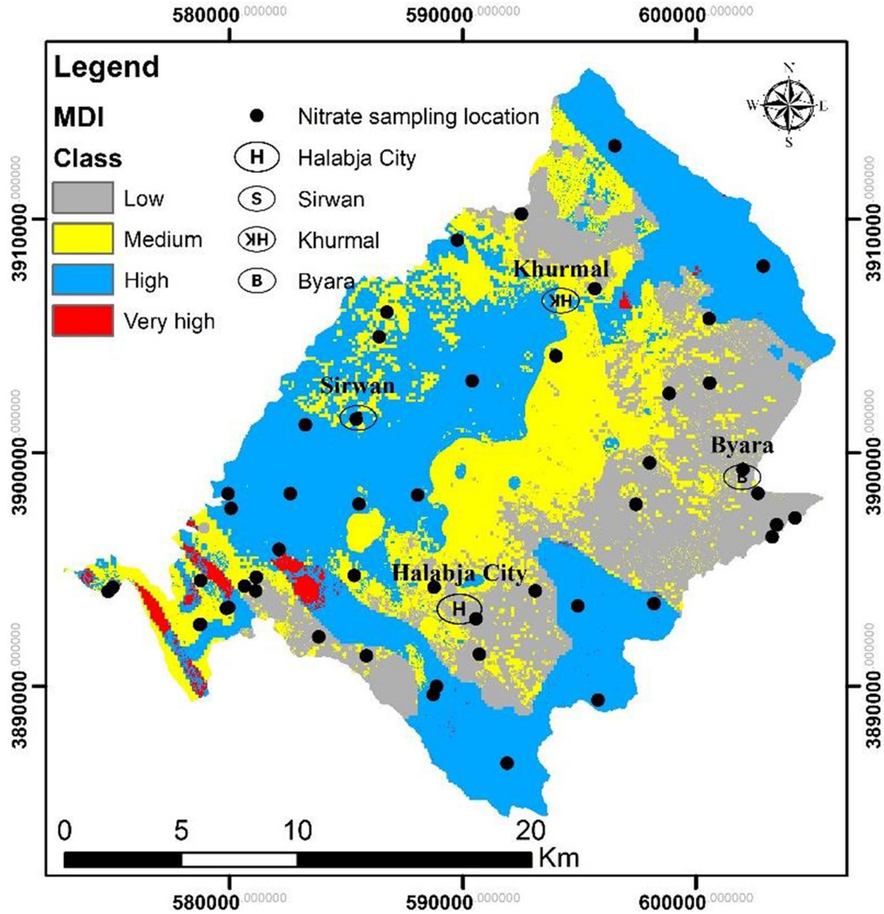

Fig. 5 Modified DRASTIC model of Halabja-Khurmal sub-basin

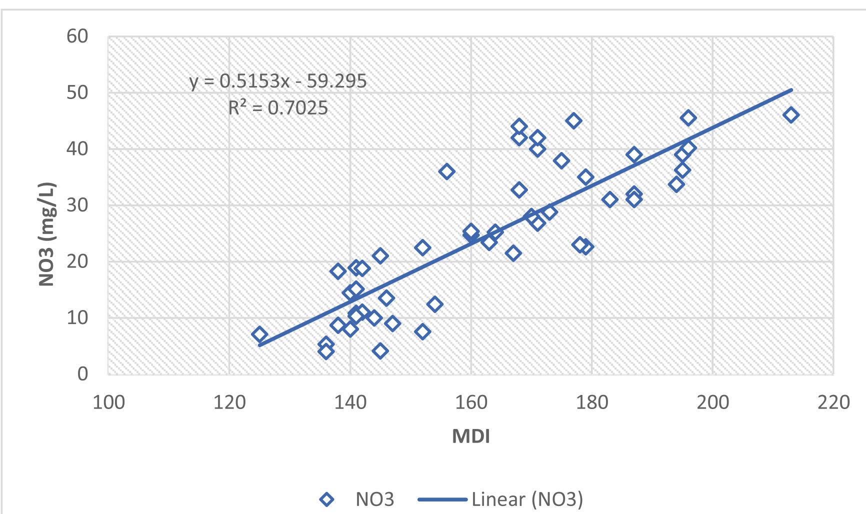

Fig. 6 Linear recession analysis of MDI and NO_3

MDI and NO_3 is 0.76 and R^2 is 0.7 from linear recession analysis (Fig. 6). Therefore, a strong direct relationship can be indicated between them, so it can be concluded that the accuracy of the models is confirmed and shows that we have achieved the purpose of the study.

5 Conclusion

Due to the importance of land use, its impact on groundwater pollution and groundwater quality, modified DRASTIC is used to evaluate groundwater vulnerability in the Halabja-Khurmal sub-basin by combining nine evaluation parameters: DRASTIC parameters, water quality index, and land use. As a result, four vulnerable zones were determined for the area. The highest vulnerability spots are located in the southwestern part of the sub-basin.

The nitrate concentration used to validate this study with a strong correlation between them indicates the suitability of this model for groundwater management and preventing groundwater pollution.

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Availability of Data The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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