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Evaluation of Groundwater Vulnerability to Pollution Using the DRASTIC Model and GIS in the Plain Part of the Khazir River Basin, Northern Iraq

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ABSTRACT

For its vastness and range of crops, the Khazir River Basin is an important agricultural region. Since groundwater supplies domestic and agricultural water, it is heavily pumped there. This study maps groundwater contamination risk and identifies high-risk locations. GIS is utilized for computations and producing maps of vulnerable water-bearing units. The most influential factors that play a major role in groundwater pollution have been considered and are the heart of DRASTIC model. A Digital Elevation Model (DEM) of 30 meters resolution is used to create the slope map (topography map) of the area. Due to the fact that the land in the study area is intensively utilized for agricultural purposes where fertilizers are always used for improving crop production, two types of DRASTIC models have been run under two scenarios, one is standard denoted as (S-DRASIC), and the other is a pesticide DRASTIC approach denoted as (P-DRASTIC). The results clearly show that the areas of shallow groundwater depths, porous aquifer media, highly permeable soil media, low slope terrains, thin and permeable vadose zone and finally an aquifer of high hydraulic conductivity revealing a high vulnerability to contamination.

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تقييم امكانية تعرض المياه الجوفية للتلوث باستخدام نموذج DRASTIC ونظام المعلومات الجغرافية GIS في الجزء السهلي لحوض نهر الخازر شمال العراق

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الملخص

يعتبر حوض نهر الخازر منطقة زراعية مهمة للغاية، سواء من حيث الحجم أو تنوع المحاصيل المزروعة هناك. ونتيجة لذلك يتم ضخ المياه الجوفية هناك بكثافة، حيث يعتبر كمصدر رئيس لمياه لاستخدام المنزلي والزراعي. الهدف من هذه الدراسة هو تحديد مدى تعرض المياه الجوفية للتلوث وتحديد المناطق الأكثر عرضة لهذه الظاهرة. ومن أجل تحقيق ذلك، تم استخدام بيئة قائمة على نظم المعلومات الجغرافية لكل من العمليات الحسابية وإنشاء خرائط المخرجات التي تمثل الوحدات الحاملة للمياه المعرضة للخطر . تم أخذ العوامل الأكثر تأثيرًا التي تلعب دورًا رئيساً في تلوث المياه الجوفية فيوهي جوهر نموذج DRASTIC. تم استخدام نموذج الارتفاع الرقمي (DEM) بدقة 30 مترًا لإنشاء خريطة المنحدر (خريطة الطبوغرافيا) للمنطقة. نظرًا لحقيقة أن الأرض في منطقة الدراسة يتم استخدامها بشكل مكثف للأغراض الزراعية حيث يتم استخدام الأسمدة بشكل دائم لتحسين إنتاج المحاصيل ، فقد تم تشغيل نوعين من نماذج DRASTIC ، أي في إطار سيناريوهين، أحدهما كمعيار ، على النحو التالي (S-DRASIC) والآخر كنهج مبيد آفات (Pesticide) DRASTIC يشار إليه باسم (P-DRASTIC). تظهر النتائج بوضوح أن المناطق ذات الاعماق الضحلة للمياه الجوفية، ووسط مسامي الخزان الجوفي، ووسط التربة عالية النفاذية، والأراضي ذات المنحدرات المنخفضة، ومنطقة الفادوز الرقيقة والنفاذة، وأخيراً طبقة المياه الجوفية ذات التوصيل الهيدروليكي العالي، تظهر قابلية عالية للتلوث.

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Introduction

When compared to surface water, groundwater has a lower vulnerability of becoming polluted, which makes it an attractive option for usage as a source of potable water. The quality of groundwater is typically susceptible to contamination, particularly in regions that are predominately agricultural and accompanied by intense utilizing of fertilizers and pesticides.

The investigated basin in northeastern Iraq (Fig.1) is a typical example of a region in which the groundwater is the primary resource of water demands for inhabitants. The development of this region in terms of population expansion, expanding rate of agriculture, and industrial activity leads to an increase in the amount of the required water, in addition to an increase in the amount of pollution that is produced.

The studies of groundwater susceptibility to contamination focus on the regions where groundwater pollution may arise. The type of contaminant is a measure of the level of vulnerability of the water-bearing formation to pollution. Accordingly, if the assessment of the vulnerability is carried out for a specific pollutant, then it is defined as a “specific vulnerability”, otherwise the “intrinsic vulnerability” is to be used instead (Focazio, et al., 2002).

Margat (1968) is credited with being the first person to introduce the idea of groundwater vulnerability to contamination. Developing aquifer vulnerability assessment maps are conducted using a variety of methods, including DRASTIC (Aller, et al., 1987), GOD (Foster, 1987), AVI (Van Stempvoort, et al., 1993), and SINTACS (Civita, 1994). These standard or conventional approaches are able to differentiate between varying degrees of vulnerability on a regional scale that involves a variety of lithologies (Vias et al 2005). DRASTIC is a well-known approach that was successfully progressed for the United States Environmental Protection Agency (EPA) by Aller, et al., (1987). This approach has been implemented in a number of different regions; (Al-Abadi, et al., 2014) who assessed the intrinsic groundwater vulnerability in northeastern Missan Governorate, southern Iraq. Hamamin, (2011) also studied the hydrogeological assessment and groundwater vulnerability of Basara Basin, Sulaimani Governorate, Iraq (Merchant, 1994; Melloul and Collin, 1998; Cameron and Peloso, 2001; Al-Adamat, et al., 2003; Baalousha, 2006; Jamrah, et al., 2007; Sener, et al., 2009; Massone, et al., 2010).

Numerous vulnerability studies have utilized the DRASTIC model in a GIS-based environment to analyze the vulnerability of groundwater to contamination in the study area (El-Naqa, A. et al., 2006; Prasad and Shukla, 2014; Awawdeh, et al., 2015; Khan, et al., 2014; Al-Rawabdeh, et al., 2013; Jaseela, et al., 2016; Al-Abadi, et al., 2014. Using groundwater vulnerability mapping based on hydrogeological characteristics that affect and govern the movement of groundwater, it is possible to identify places that are more susceptible to contamination (Aller, et al., 1987).

In recent years, groundwater vulnerability maps have gained widespread acceptance as a tool in the process of land use planning. An evaluation of the susceptibility of groundwater to contamination by pollutants is necessary for determining the likelihood of groundwater contamination and is therefore vital for groundwater management and the protection of groundwater quality (Fobe and Goossens, 1990; Worrall, et al., 2002; Worrall and Besien, 2004).

The purpose of this research is to conduct an analysis of the sensitivity of the groundwater in the Khazir River Basin to pollution using two different scenarios: the standard and pesticide DRASTIC approaches. The DRASTIC model and techniques from geographic information systems (GIS) are integrated with hydrogeological data layers in order to accomplish this goal. The delineation of contamination vulnerability zones is an extremely important step that must be taken to protect and effectively manage the water-bearing formations' system in the region.

Description of the Study area

The Khazir river basin (Fig. 1) is situated in northern Iraq, within Duhok Governorate in the Kurdistan Region. The research area is a part of Khazir Basin with a total area of approximately 1047 km2. The Khazir River separates the area into two sections, the left-bank section belonging to the Aqra plain and the right-bank section to the Shekhan district. The region is bordered to the north by the Aqra Mountains and to the south by the Maqlob Mountains. From a geographical standpoint, the region lies between 36° 29' 00" and 36° 51' 00" North and 43° 27' 00" and 43° 52' 00" East.

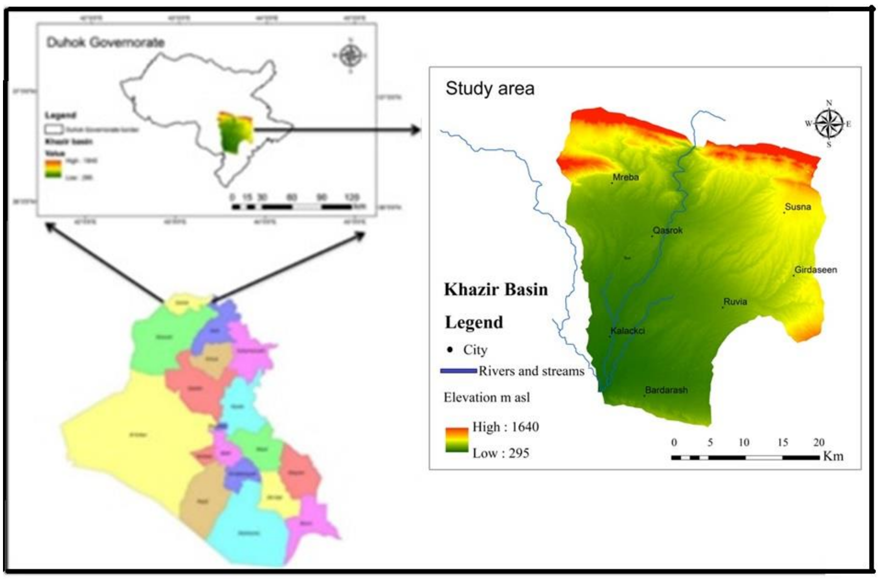

Fig.1. Location map of the research area (after Younis and Ahmed, 2022)

The greatest tributary of the Greater Zab River is Khazir River which receives water from an area of approximately 2900 km^2. Khazir spans 96 kilometers. Almost one half of the river's length travels through the area under study before it joins up with one of its tributaries, the Gomel River.

The northern region of the study area is an orographic zone with the outcrops of Aqra-Bekhme, Qamchuqa Cretaceous, and Pila Spi (Middle Eocene) geologic formation. The fractured aquifer system is made up of several limestone deposits. The remainder of the region is a Pliocene (Bai Hassan and Makdadiyah formations (previously Bakhtiari Group) and Quaternary agricultural plain (Figures 2 and 3). Brief description of the Tertiary and Quaternary formations is described in Table (1).

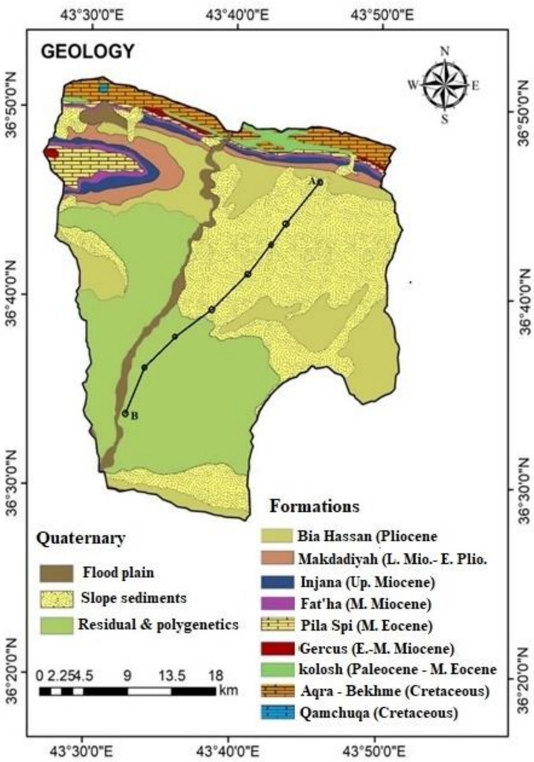

Fig. 2. Geological map of the study area, Iraqi Geological Survey in (Younis and Ahmed., 2022)

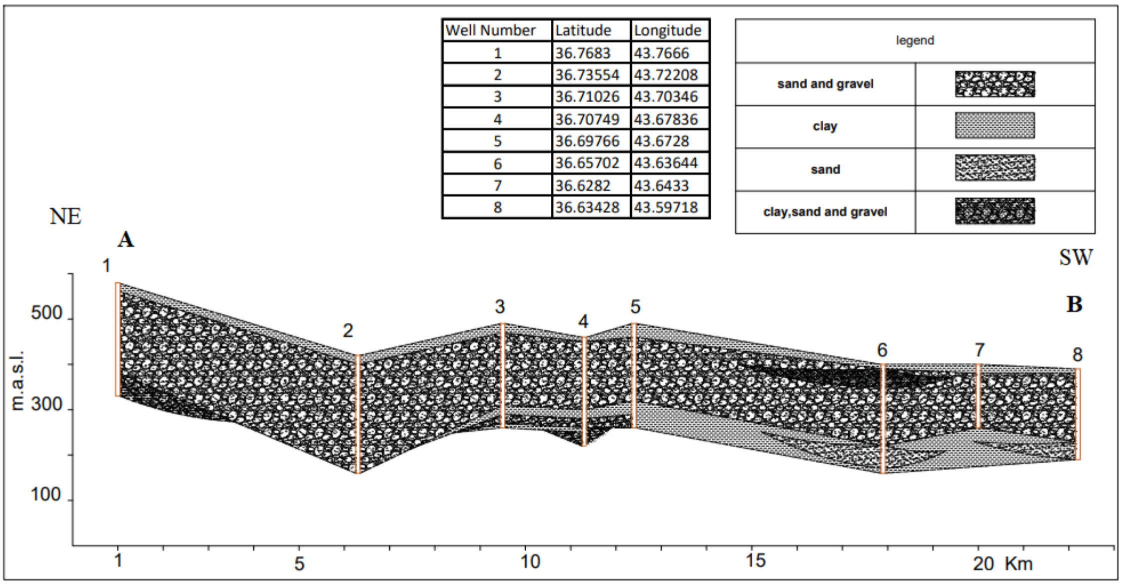

Fig. 3. Geologic cross-section of study area obtained from the productive well logs with their coordinates shown in the figure (well profiles obtained from General Directorate of Groundwater in Duhok) (Younis and Ahmed, 2022)

Table 1: Summary of the geology of the study area

Era	Period	Epoch	Age	Formation	Lithology
CENOZOIC	Quaternary	Holocene		Younger Alluvium	River's flood plain sediments mainly rock fragments gravel, sand silt and clay
		Pleistocene		Older Alluvium	River's flood plain terraces composed mainly of rock fragments gravel, sand silt and clay
	TERTIARY – Neogene	Pliocene	Late	Upper Bakhtiari/ Bai Hassan	Alternation or compacted conglomerate and brown compacted claystone. Grey course sandstone
			Early	Lower Bakhtiari/Makdadiyah	Gravely sandstone, sandstone and red mudstone. Sandstones are strongly cross-bedded.
		Miocene	Late	Upper Fars/ Injana	The basal unit comprises thin-bedded calc. sandstone, and red and green mudstone with very thin gypsum bed. Purple Siltstone
			Middle	Lower Fars/Fatha	gypsum and anhydrite interbedded with limestone and marl
			Early		
	TERTIARY – Paleogene	Oligocene			
		Eocene	Late	Pila Spi Limestone	Dolomitic and chalky limestone with chert nodules
			Middle	Gercus Red Bed	Red clastic sandstone and claystone, red and purple shale with gypsum lenses. Basal conglomerates exist as well.
			Early	Kolosh	Shales, sandstones, chert, radiolarite.
		Paleocene		Khurmala	lagoonal crystallized limestone, dolomite with interbeds of different clastic rocks.

Material and Methods

The vulnerability of groundwater to contamination has been studied by hydrogeologists and environmental scientists since when groundwater was taken as an alternative for drinking and irrigation purposes. Conventional methods for determining groundwater vulnerability to contamination are expensive and need longer time compared to GIS-based methods.

DRASTIC model, which is based on GIS, has been utilized in this work to evaluate the degree of vulnerability to groundwater contamination. The flowchart d in Figure (4) provides a broad outline of the study technique, and table (2) provides the data that is required to be used in mapping the groundwater vulnerability. This approach relies on some parameters that control the presence of groundwater in the system as well as its mobility. DRASTIC is the abbreviation of the seven parameters involved in the model and has an impact on the vulnerability of groundwater to contamination. (D) stands for the depth of the groundwater, (R) for the net recharge, (A) for the aquifer media, (S) for the Soil media, (T) for topography, (I) for the Impact of the vadose zone, and (C) for the hydraulic conductivity. Each parameter involved in DRASTIC model holds two values, the first is for rating while the second is for weighting. The former ranges between one to ten determining the strength of the parameter to have its impact on groundwater vulnerability.

The model uses a weighting value that is a constant number between 1 and 5, therefore, the value of the parameter's weighting will remain the same regardless of the rating value that is assigned to it. The most significant factor holds a weight of 5, whereas the least important factor has a weight of 1.

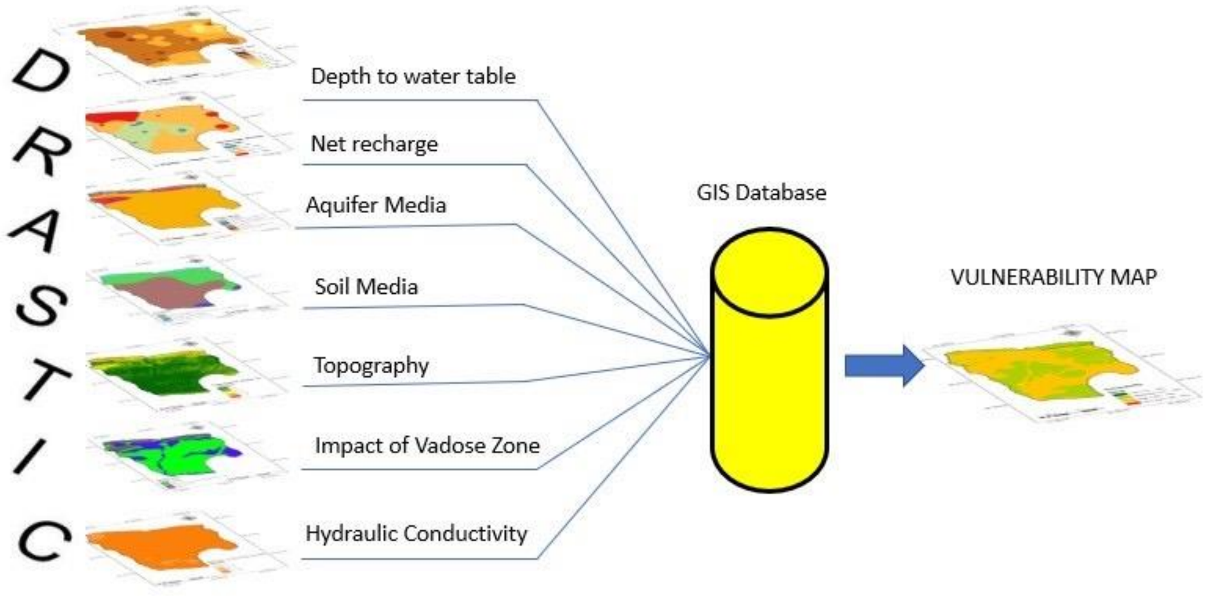

Fig .4. Flowchart of DRASTIC methodology

Table 2: List of the data sources

Elements	Source
Depth to Groundwater	Achieves of Groundwater Directorate in Duhok with data from field
Net Recharge	Previous PhD Thesis (Yousuf,2021)
Aquifer Media	Boreholes lithologic section
Soil Map	FAO (2001)
Topography	DEM (30m) resolution
Impact of Vadose zone	Boreholes lithologic section
Hydraulic Conductivity	Aller et al.,1987

The level of agricultural activities in the area throughout the using of fertilizers or not, decides which version of DRASTIC model to be used, either the standard one for normal conditions or the DRASTIC model that has been set up for agricultural areas with extreme utilization of pesticides. The attribution of relative weights to the seven DRASTIC criteria differs between the two versions of DRASTIC. Using pesticides in regions with poor groundwater protection can have a major impact on the water quality. Water containing these contaminants will seep down into the soil. When the agricultural activities are concerned in an area the P-DRASTIC model version is recommended to be used. This type represents a specific case of DRASTIC Index. The essential difference between S-DRASTIC and P-DRASTIC is in the values of weights that are given to the seven factors involved in the model. It should be mentioned here that the ranges and ratings will stay having the same values. From table (3), the soil media are given a weight of 2 for non-agricultural regions, while is given a value of 5 for the P-DRASTIC version. There are slight differences in the weighting values of the impact of vadose zone media, topography, and the hydraulic conductivity of the aquifer.

Below is the algorithm used to estimate the final vulnerability index “DRASTIC Index”, which is a weighted sum of the whole seven factors:

$$DRASTIC\ Index = \boldsymbol{D_r}.\boldsymbol{D_w} + \boldsymbol{R_r}.\boldsymbol{R_W} + \boldsymbol{A_r}.\boldsymbol{A_w} + \boldsymbol{S_r}.\boldsymbol{S_w} + \boldsymbol{T_r}.\boldsymbol{T_w} + \boldsymbol{I_r}.\boldsymbol{I_w} + \boldsymbol{C_{w.}}\boldsymbol{C_r} \quad \ldots (1)$$

Where D, R, A, S, T, and I are the seven involved parameters, and the subscripts r and w are the relative ratings and weights for each parameter.

Table 3: The values of acting and weight rates used in DRASTIC model

Factors	Range	Rating	Weight	Pesticide weight
Depth to Gw(m)	0-5	10	5	5
	5_15	9		
	15-30	7		
	30-50	5		
	50-75	3		
	75-100	2		
	>100	1		
Net recharge (mm)	0-50	1	4	4
	50-100	3		
	100-175	6		
	175-250	8		
Aquifer Media	Sand & Gravel	8	3	3
	Aqra& Bekhme fm	1		
	Fatha fm	2		
	Gercus fm	1		
	Bedded Limestone	7		
	Qamchuqa fm	1		
Soil Media	Rough broken stony land	10	2	5
	Brown soil medium- shallow phase over Bakhtiyari gravel	9		
	Brown soil deep phase	7		
	Lithosolic soil in limestone	4		
Topography %	0-2	10	1	3
	2-6	9		
	6-12	5		
	12-18	3		
	>18	1		
Vadose zone	Sand & Gravel	8	5	4
	Sand & Gravel with significant Silt & Clay	6		
	Limestone	6		
	Silt/Clay	3		
Hydraulic Conductivity m/day	4-12	2	3	2
	12-29	4		
	29-41	6		
	41-82	8		
	>82	10		

Preparation of thematic layers

Depth to water table (D)

The depth to the water table can be defined as the vertical distance between the ground surface and the groundwater table, while it represents the vertical distance to the bottom of the confining bed in confined aquifers. The depth to water is a significant factor mainly because it reflects the depth of media through which a pollutant would pass before reaching the groundwater. The shallower the water depth is, the more susceptiblity the contamination of the aquifer from outside sources, and vice versa.

The information regarding the level of the groundwater is obtained from 49 wells, supplied by Groundwater Directorate in Duhok. The selected boreholes are randomly distributed in the study area which have been used for monitoring and recording then interpolation in GIS environment to obtain the water-table map in a raster format. The Inverse Distance Weighted (IDW) has been used as an interpolation technique. Thereafter, raster map is reclassified using the ranges and ratings recommended by Aller et al. (1987) (Table 3).

Seven classes have been considered for the depth of the groundwater in the study area which are: (1-10), (11- 20), (21-35), (36-60), (61-75), (76-100), and (> 100) m (Fig.5a).

Net Recharge (R)

The annual quantity of water per unit area that makes its way to reach the water table is referred to as the "net recharge" and it is measured in millimeters. The net recharge parameter is estimated from infiltration data obtained from Yousuf (2021). The direct average annual volume of recharge comes from the precipitation and reaches the aquifer is 121.18 mm. IDW is also utilized to do an interpolation on the data pertaining to the net recharge, then classified according to the ranges and ratings suggested by Aller et al. (1987) (Fig.5b).

Aquifer media (A)

The rock that constitutes an aquifer, regardless of whether it is consolidated or not, is referred to as the "aquifer medium". A geologic formation is said to be an aquifer if it possesses sufficient saturated permeable material to supply considerable quantities of water to wells and springs. The lithological section of pumping wells served as the foundation for the categorizing of this parameter, which was then used to generate a polygonal distribution over the region.

According to the lithologic section obtained from the pumping wells provided by the General Directorate of Groundwater in Duhok, two aquifer media have been considered, sand & gravel and bedded limestone. Therefore, the rating is given according to Aller et al. (1987). Due to the fact that no production wells are available in Fatha, Gercus, Qamchuqa and Aqra-Bekhme formations, the rating values therefore are given according to the lithology of the formation.

Eventually, the raster map has been generated from polygon map throughout using of the “raster tool” (Fig.5c).

Soil media (S)

The term "soil" refers to the aggregate of mineral particles, organic matter, air, and water that composes the uppermost layer of the majority of land that is essential for the development of plant life. The soil profile is made up of several layersbeginning at the top and going all the way down to the underlying rock. The topmost part of the vadose zone with the greatest level of biological activity is referred to as the "soil media". The average thickness of soil measured from the ground surfaceis about 150 cm. The soil has a substantial impact on both the amount of recharge water that is able to seep into the ground and the ability of a pollutant to migrate vertically into the vadose zone as a direct result.

For this study, the soil map of Iraq prepared by FAO (2001), is used as a source for classifying the soil media of the area under study. Accordingly, four different classes of soil media (Fig. 5d) have been categorized: rough, broken and stony land; brown soil medium and shallow phase over Bakhtiyari gravel; brown soil deep phase; and lithosolic soil in limestone given the rating of (10, 9,7 and 4) respectively as proposed by Aller et al. (1987).

Topography (T)

The influence of topography is distinctive on whether a pollutant can last longer on the ground surface and gets a higher opportunity to be leached or to infiltrate into the ground. If the topography or the slope is gentle, that will be associated with a higher ground-water pollution potential. On the contrary, if the slope of the landscape is steep, the contaminants will runoff and reduce the vulnerability of groundwater to pollution.

Arc GIS 10.6 is used to determine the percentage of slope using a (30) m cell size digital elevation model (DEM). The resulting slope map is reclassified according to table (3) in order to generate the slope ratings map. Accordingly, the topography (slope) of the region id divided into five classes, with percentages ranging from 0 to 2, 2 to 6, 6 to 12, 12 to 18 and greater than 18 percent as shown in figure (5e).

Impact of Vadose Zone (I)

Vadose zone facilitates the transfer of recharging water and contaminants from the land surface to the groundwater below. According to a study of Małecki and Matyjasik (2003), the average total dissolved solids values for precipitation ranged from 30.2 mg/l at the land surface to 318 mg/l in groundwater. This means that there is a dramatic change in the hydrogeochemical composition of the water through its percolation in the vadose zone.

The thickness of the vadose zone ranges from very shallow to more than 100 m depending on the depth of the water table (Holden and Fierer, 2005). In cases of very shallow groundwater tables, the thickness of this zone becomes less than 1m, while in deep water table conditions the thickness may reach tens of meters. Figure (5a) clearly shows the spatial distribution of the thickness of this zone in the study area. Vadose zone is an unsaturated zone which serving mainly as a zone connecting the soil zone, which is near the ground surface, with the zone of saturation where water table is its upper boundary. The texture of vadose zone determines how easily and fast the contaminant can move downwards to reach the groundwater.

The type and texture of the vadose zone's regolith or bedrocks are derived from the lithologic logs of boreholes and the geologic map of the region. The rating values are given to each type according to Aller et al. (1987) as shown in figure (5f).

Hydraulic conductivity (C)

Hydraulic conductivity is a term used to describe the capacity of a soil or rock to permit the movement of water through it. Therefore, this parameter determines how easily the contaminant will disperse and convey in the aquifer. Accordingly, the higher the hydraulic conductivity, the more vulnerable the aquifer is.

Values of hydraulic conductivity parameter are generally estimated from pumping test analysis. As far the authors could not find any published work that would be reliable to be used as a spatial distribution of hydraulic conductivity parameter, therefore the values for hydraulic conductivity are estimated from the combination of values given in Table (4), and the reasonable representative values given in Table (12) in Aller et al. (1987).

The hydraulic conductivity within the study area ranges between <12 to less than 140 m/day (Fig. 5g).

Table 4: Representative Values of Hydraulic Conductivity (after Morris and Johnson, 1967)

Material	Hydraulic conductivity (m/day)
Gravel, coarse	150
Gravel, medium	270
Gravel, fine	450
Sand, coarse	45
Sand, medium	12
Sand, fine	2.5
silt	0.08
Clay	0.0002
Sandstone, fine-grained	0.2
Sandstone, medium-grained	3.1
Limestone	0.94
Dolomite	0.001

Results and Discussion

As a result of the presence of both industrial and agricultural operations in the area under investigation, the DRASTIC model for vulnerability assessment has been adapted in this particular study to include both a standard version as well as a pesticides version. ArcGIS has been used for creating DRASTIC raster map layers. DRASTIC criteria provided by Aller, et al. (1987) ratings and weights are applied. The overall cell rating is calculated by adding the ratings for each DRASTIC parameter. The rating ranges from 1 to 10 is shown on the maps for all parameters.

Figure (5a) shows the study area's depth to the groundwater map. The data show that 61% of the region has groundwater depth between 1 and 30 m, 30% between 30 and 50 m, and a relatively small portion between 50 and 100 m. This map represents water table depth-based rating classes 1–10. The shallow water table in the northern and central study area increases groundwater pollution potential with high scores (10 to 7). A small percentage of the study region, mainly the northeastern part, has a deeper water table with a rating of 1. Only the middle half of the research region has water table depths from 30 to 100 m with ratings of 5 to 2.

Figure (5b) illustrates the net recharge map with four rating classes (1, 3, 6, and 8). Both the standard and pesticide DRASTIC models gave the recharge parameter a weight of 4 (Table 3). The northwest area has the highest score (8), associated with the type of geological unit (Pila Spi limestone) which is characterized by the presence of karst, joints and fractures; therefore, this limestone transfers a lot of precipitation to groundwater. About 61% of the area has a middle net recharge ranging from 100-175 mm/y with a score 6, and 24% has a score of 3. minimum values have been noticed in some areas, as well as the center of the towns and other urbanized areas, due to the fact that the soil has been covered by constructions or asphalts which impedes the infiltration of water.

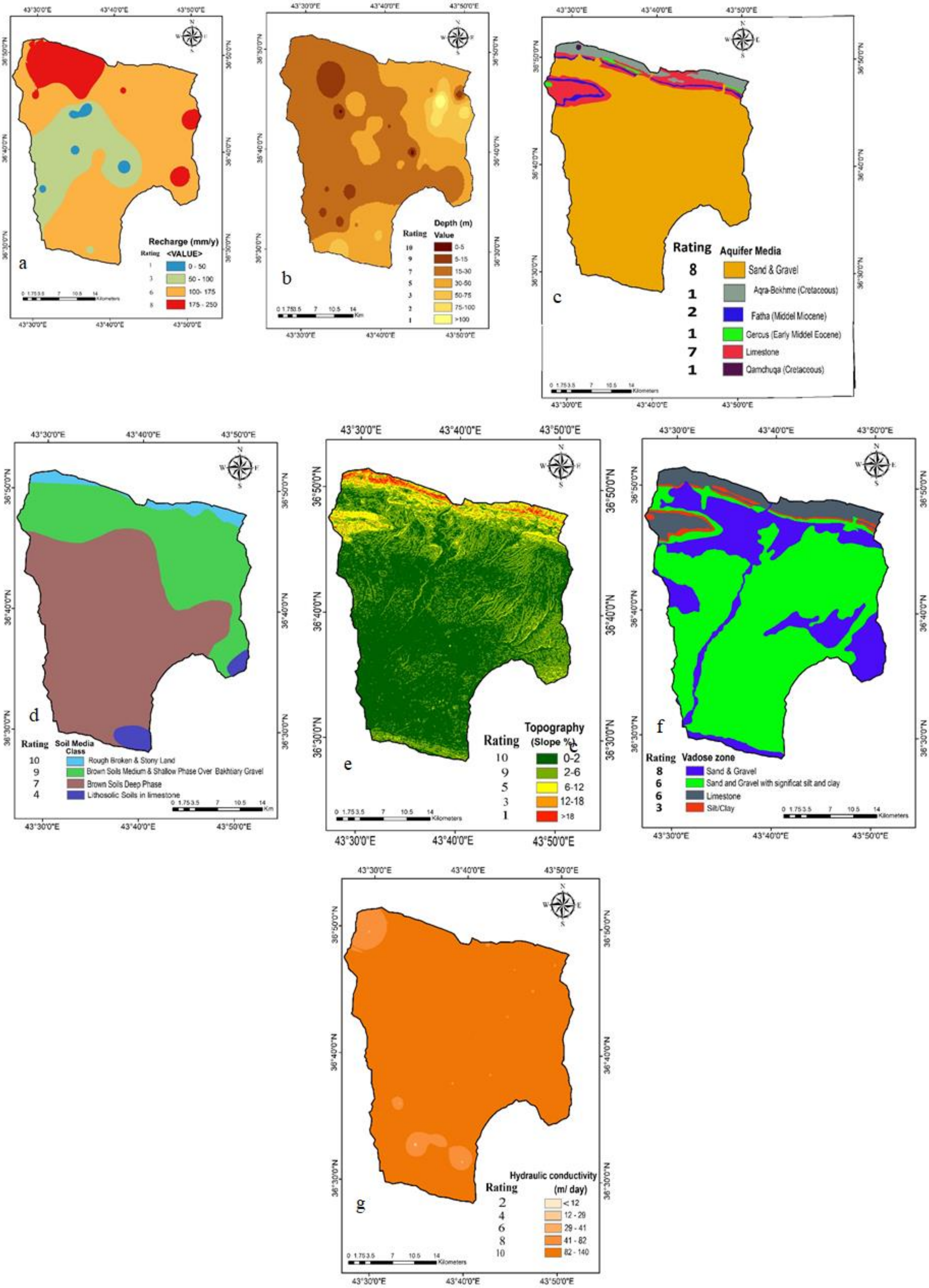

Fig .5. DRASTIC range and rating maps (a) depth to the groundwater (b) Net recharge (c) Aquifer media (d) Soil media (e) topography (f) Impact of vadose zone (g) Hydraulic conductivity

In both types of DRASTIC techniques, the "3" weight was designated for the aquifer media parameter (Table 3). According to the map, there are two distinct forms of aquifer media, which are designated as sand and gravel and bedded limestone, these two types have ratings of 8 and 7, respectively (Fig. 5c). Sand and gravel with a rating of "8" have a substantial potential for contaminating groundwater, and this makes up the majority of the research area, which is around 87%. In the contrary, Pila Spi Formation of bedded limestone with a rating value of 7 belongs to the second order and covers approximately 7 percent of the north and northwestern portion of the research area.

The soil medium parameter was weighted "2" in the standard technique and "5" in the pesticide DRASTIC method (Table 3). Figure (5d) shows four soil ratings in the area under study. Rough fractured rocky terrain in mountainous areas, brown soil medium-shallow phase over Bai Hassan or Muqdadiyah gravel in the areas between the middle part and the highly altitude areas, brown soil deep phase in the central region, and lithosolic soil in limestone, each covers 3%, 34%, 60%, and 3% of the total area respectively with ratings of 10,9,7, and 4 respectively.

The term "topography" refers to the variable slopes of the ground surface. A weight of "1" was given to the topographical parameter in the generic DRASTIC model, while a weight of "3" was given to the topography parameter in the pesticide DRASTIC model. Figure (5e) represents the topographic map of the study area. The data indicates that 41% of the land has a slope between 2% and 6%, whilst 24% of the area has a slope between 0% and 2%. The slope ranging from 6% to 18% covers approximately 25% of the land. Only (9%) of the area under study has a slope that is steeper than (18%). The rating values corresponding to each slope range are 1, 3, 5, 9, and 10. The higher the altitude the steeper the slope or the topography, therefore, the gentler areas are in the middle and southern parts of the area close the outlet point of Khazir River.

In the standard approach, vadose zone media was given a weight of "5", whereas in the pesticide DRASTIC method, it was given a weight of "4". According to figure (5f) of the vadose zone map, it has been noticed that the vadose zone is made of four distinct segments: sand and gravel, sand & gravel with significant silt & clay, limestone, and silt/clay. The generated map exhibits ordered variation in vadose zone rates of 8, 6, and 3 respectively.

Due to differences in the aquifer's hydraulic conductivity, the region is separated into five zones as shown in figure (5g). These zones have hydraulic conductivities of (4 - 12), (12 - 29), (29 - 41), (41 - 82), and greater than (82) m/d with respective ratings of (2,4,6,8, and 10). The DRASTIC application of this parameter was given a weight of 3 for the standard approach and 2 for the pesticide one.

GIS spatial analyst's weighted sum capability is used to generate the final vulnerability map of the study area for both DRASTIC versions, the standard and pesticide. The rating value of each input layer has been multiplied by the weight of its corresponding layer, then they have been summed out to obtain the DRASTIC index. For the purpose of creating vulnerability classes, the resulting indices are categorized in accordance (Table 5).

Table 5. DRASTIC Index and vulnerability classes (Civita and De Regibus, 1995; in Al-Abadi et al., 2014)

DRASTIC Index	Vulnerability classes
<80	Very low
80-125	Low
125-160	Moderate
160-200	High
>200	Very high

Figures (6a and b), respectively display the vulnerability classes for standard and pesticides DRASTIC. The areas that are occupied by each of these classes are outlined in Table (6), which compares the pesticide version of the DRASTIC model to the standard version.

Table 6: DRASTIC vulnerability classes of the study area and the area occupied by each class

DRASTIC version	Vulnerability classes	Area km^2	Area %
Standard	Low	3	0.33
	Moderate	482	46
	High	560	53.6
	Very high	0.3	0.03
Pesticide	Moderate	44	4
	High	888	85
	Very high	113	11

The results of this study show that the vulnerability of groundwater to pollutants using the standard DRASTIC approach is categorized into four zones of vulnerability: low, moderate, high, and very high. DRASTIC Index ranges from 110 to 543 (Fig. 6a).

According to the results presented in Table (6), 0.33 percent, 46%, 53.6 percent, and 0.03 percent of the research area, respectively, fall into the low, moderate, high, and very high classes of groundwater vulnerability to contamination. It is possible to link the impact of the vadose zone, low slope percentage, and low depth to groundwater to the fact that a large region, comprising 53% of the total, is found inside the high vulnerability class.

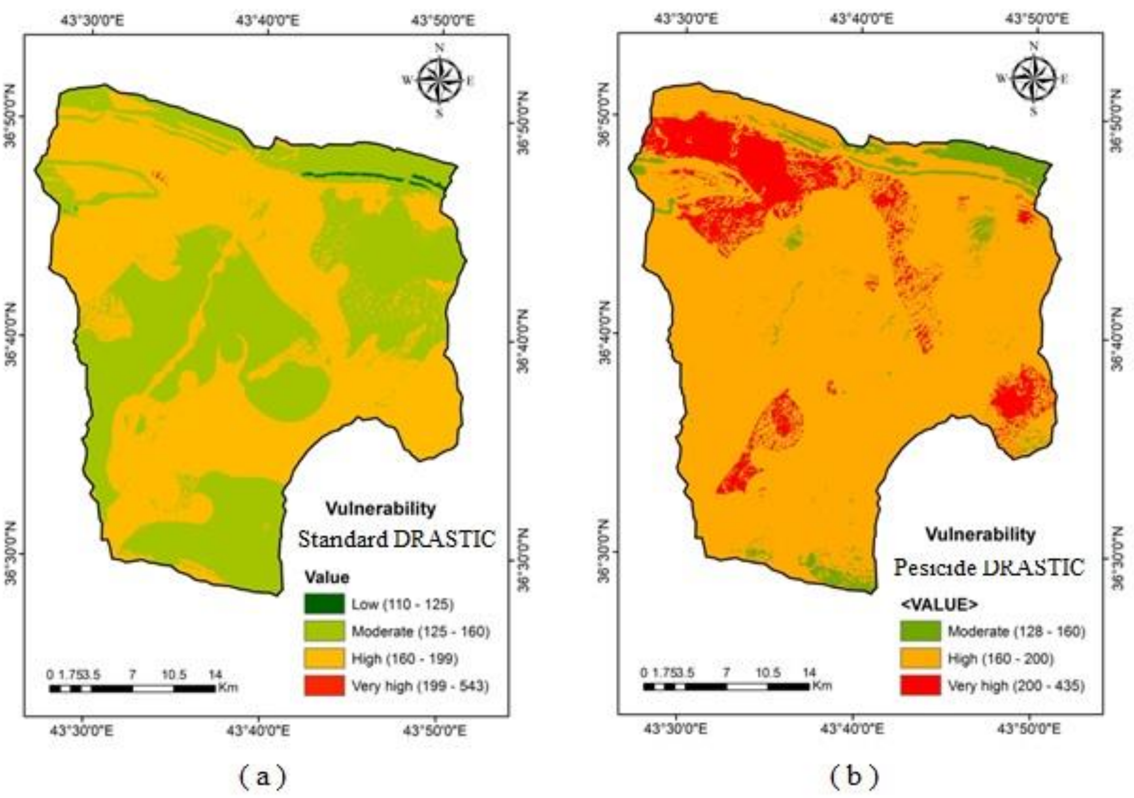

Fig .6 .Groundwater vulnerability to contamination map (a) Standard DRASTIC method (b) Pesticide DRASTIC method.

The pesticides DRASTIC index map (Fig. 6b) reveals that the studied region is comprised of three distinct zones of vulnerability: moderate, high, and very high. The DRASTIC index for pesticides varies from a low of 128 to a high of 435. The map that was produced as a consequence of this version of DRASTIC makes it abundantly evident that, respectively, 4%, 85%, and 11% of the research area have a moderate vulnerability to contamination, a high vulnerability to contamination, and a very high vulnerability to contamination.

Model Validation

Natural waters are never completely free of impurities; there is always some quantity of dissolved gas or mineral present in them (Fetter, 2001). The chemical and biological components of groundwater are what define its utility for a variety of purposes, including drinking, irrigation, and industrial and domestic purposes.

Groundwater nitrate concentrations were taken and compared to the model's result (vulnerability index) to verify the model's accuracy. This comparison was performed using the Nitrate data that was obtained by the Directorate of Environment in the Duhok Governorate. Nitrate (NO_3) is one of the most important indicators of the contamination of water resources. Instead of coming from dissolved minerals, it is introduced into the water supply through a process known as the nitrogen cycle (Secunda, et al., 1998). Although some point sources of nitrogen, such as septic systems, contribute to the nitrate contamination of groundwater (Chowdany, et al., 2005), the majority of the nitrate in groundwater comes from fertilizers that have been applied to agricultural areas (Postma, et al., 1991; Baker, 1992; Hubbard and Sheridan, 1994). Figure (7) shows the distribution of NO_3 concentrations across the study area.

The World Health Organization (WHO) and Iraqi drinking water guidelines set the maximum allowable quantity of NO_3 in drinking water at less than 50 mg/l. The concentration of nitrate as (NO_3) in natural groundwater is less than 10 mg/l. If this rate increases in groundwater, that means an external source of this compound has contributed to change the hydrogeochemical condition of the system.

Samples of shallow groundwater from 124 different wells were tested and analyzed to determine the nitrate (NO_3) concentration in the water. The General Directorate of Environment in Duhok Governorate was responsible for carrying out a periodic monitoring for the analysis of the water samples on behalf of the General Directorate of Groundwater, which is the organization that contributed the data that have been used for this study. The spectrophotometric approach is utilized in order to ascertain the levels of nitrate oxide present in the groundwater. The measured nitrate concentrations are utilized to establish a relation between the pollution in the groundwater and the derived DRASTIC index using both the traditional and the pesticide DRASTIC models. The nitrate concentration map clearly shows that the rate of this oxide is higher than 10 mg/l in major parts of the study area, that means the agricultural activities and hence the using of fertilizers are the main sources of increasing nitrates in groundwater. Therefore, in the very near future, unless some steps to be implemented to reduce utilizing these fertilizing compounds, the groundwater will be not suitable for some purposes particularly as a potable water.

The maps of both scenarios clearly show that in the areas where agricultural pesticides are still being used, or will be used more, and unless radical solutions should be implemented to reduce the risks, the future of the groundwater resources will be in danger, this is due to the fact that in this area, where the vulnerability is high, the rate of NO_3 concentration is high. This means that the source of pollution is still present.

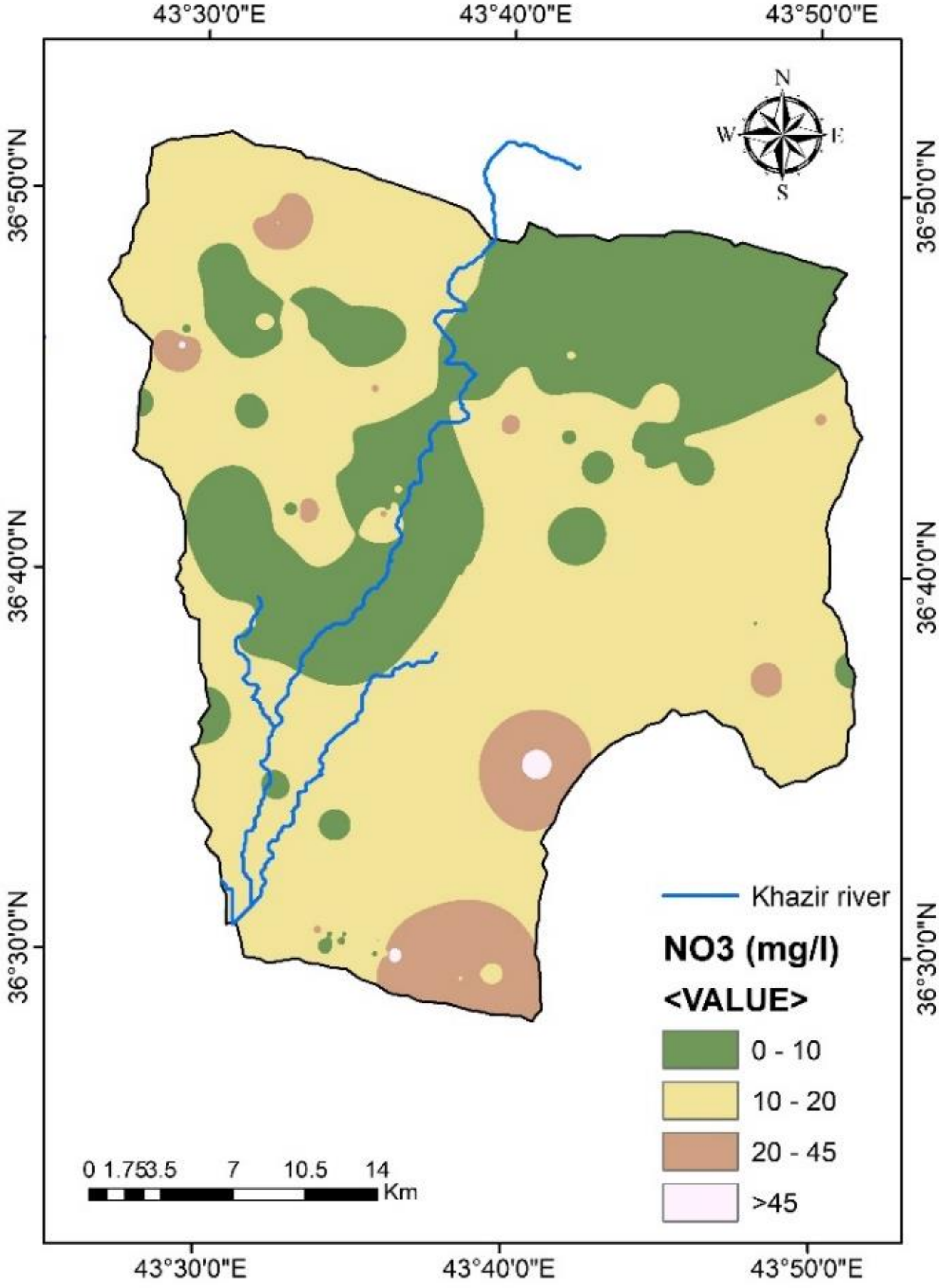

Fig. 7. Nitrate concentrations in groundwater of the study area.

Conclusions

For the purpose of calculating the degree to which groundwater is susceptible to contamination, a GIS-based DRASTIC model was utilized. The study region has been categorized into four zones (low, moderate, high, and very high) using the Standard DRASTIC approach, whereas three zones have been identified using the Pesticide DRASTIC model. This has been carried out on the basis of the relative groundwater vulnerability index to contamination.

The vulnerability index is a measure of how likely the groundwater may be contaminated. The risk increases as the vulnerability index number increases. According to the findings, the most extensive proportion of the land belongs to the highly vulnerable class, which accounts for 53.6% and 85% of the entire land area for both Standard and Pesticide DRASTIC model respectively. Additionally, a large portion of the territory is comprised of the moderate vulnerability class in standard DRASTIC scenario. In the Khazir basin, the groundwater system is an essential component of the drinking water supply. The study's conclusions suggest that the GIS-based DRASTIC model could be used to identify vulnerable locations for the management of groundwater quality. In places that are particularly at risk, it is imperative that groundwater should be subjected to in-depth and consistent testing in order to track the fluctuating concentrations of pollutants. In addition to that, the current study contributes to the selection process that is used to identify dump sites and landfills.

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