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Identification of Vulnerable Zones for Groundwater Using a GIS-based DRASTIC Technique in Shwan Sub-basin/North-Iraq

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Abstract

Groundwater is considered as one of the most important sources of fresh-water, on which many regions around the world depend, especially in semi-arid and arid regions. Protecting and maintaining groundwater is a difficult process, but it is very important to maintain an important source of water. The current study aims to assess the susceptibility of groundwater to pollution using the DRASTIC model along with the GIS environments and its tool boxes. A vulnerability map was created by relying on data collected from 55 wells surveyed by the researchers as well as archived records from governmental institutions and some international organizations. The results indicate that the region falls into three vulnerability functional zones, namely very low, low and medium. Fortunately, most of the region is in a very low - low range (89-125) which covers approximately 94.6% of total area of the region, while the medium zone (125-133) forms 5.4%, as the smallest part of the total area of region. To reduce the risk of pollution in the medium zones of vulnerability, precautionary measures must be taken before commencing industrial or agricultural activities.

Keywords: Vulnerability, DRASTIC Model, Inter granular aquifer, Function zoning, Shwan sub-basin.

تحديد انطقة المياه الجوفية الأكثر عرضة للتلوث بأستخدام تقنية (DRASTIC) المستندة الى نظم

المعلومات الجغرافية في حوض شوان الثانوي/العراق

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الخلاصة

تعتبر المياه الجوفية واحدة من اهم مصادر المياه العذبة والتي يعتمد عليها كمصدر للمياه في العديد من المناطق حول العالم و خصوصا في المناطق الجافة والشبه جافة. ان حماية المياه الجوفية و الحفاظ عليها عملية صعبة، ولكنها مهمة جدا للحفاظ على مصدر مهم للمياه. تهدف هذه الدراسة الى تقييم مدى امكانية المياه الجوفية على التلوث عن طريق نموذج (DRASTIC) وبأستخدام برنامج نظم المعلومات الجغرافية. تم انشاء خريطة الضعف لمنطقة الدراسة بالاعتماد على البيانات المأخوذة من قبل الباحثين لـ 55 بئرا، ومن سجلات الحفر الموثقة في الدوائر الحكومية ومن الوزارات العراقية بالإضافة الى بعض المنظمات الدولية.

تشير النتائج الى ان المنطقة تقع ضمن ثلاث من اربعة المنخفضات "المنخفضة جدا ، المنخفضة ، المتوسطة" .
 لحسن الحظ ان اغلب اجزاء المنطقة تقع ضمن النطاق "المنخفض جدا - منخفض" بين "89-100" بينما
 يشكل النطاق المتوسط للضعف (125-133) جزء صغير جدا من مساحة المنطقة. للحد من مخاطر التلوث
 في مناطق الضعف المتوسطة ، يجب اتخاذ تدابير وقائية قبل البدء في الأنشطة الصناعية أو الزراعية.

Introduction

The vulnerability map is considered as a valuable tool in environmental management and constitutes an important part of water protection schemes [1]. Many studies described freshwater availability in terms of type, quantity, and quality, which can possibly deteriorate due to the spatial and temporal changes in the water availability [2]. Vulnerability maps are used to determine the area of potential groundwater pollution. To keep the groundwater from pollution, groundwater vulnerability assessment can act as the most helpful and realistic tool [3, 4, 5, 6, 7, 8, 9]. Vulnerability is defined as the natural failure to protect groundwater against the risks of pollution due to the local hydrogeological conditions [10]. Margate [11] was the first author to apply the concept of groundwater vulnerability in France in 1968. After that, several methodologies appeared to develop maps of the vulnerability assessment of the aquifer, such as DRASTIC [12], GOD [13], SINTACS [14], AVI" [15], etc.

Shwan sub-basin is located in the North-Eastern part of Iraq, within Kirkuk governorate. It covers an area of about 768 km². Many commercial industries in addition to agricultural activities occupy large parts of the area of interest, which is shown in Figure 1. The meteorology of the Shwan sub-basin is under the influence of the Mediterranean climate which is described as hot and dry, with long summers as well as cold and wet winters [16].

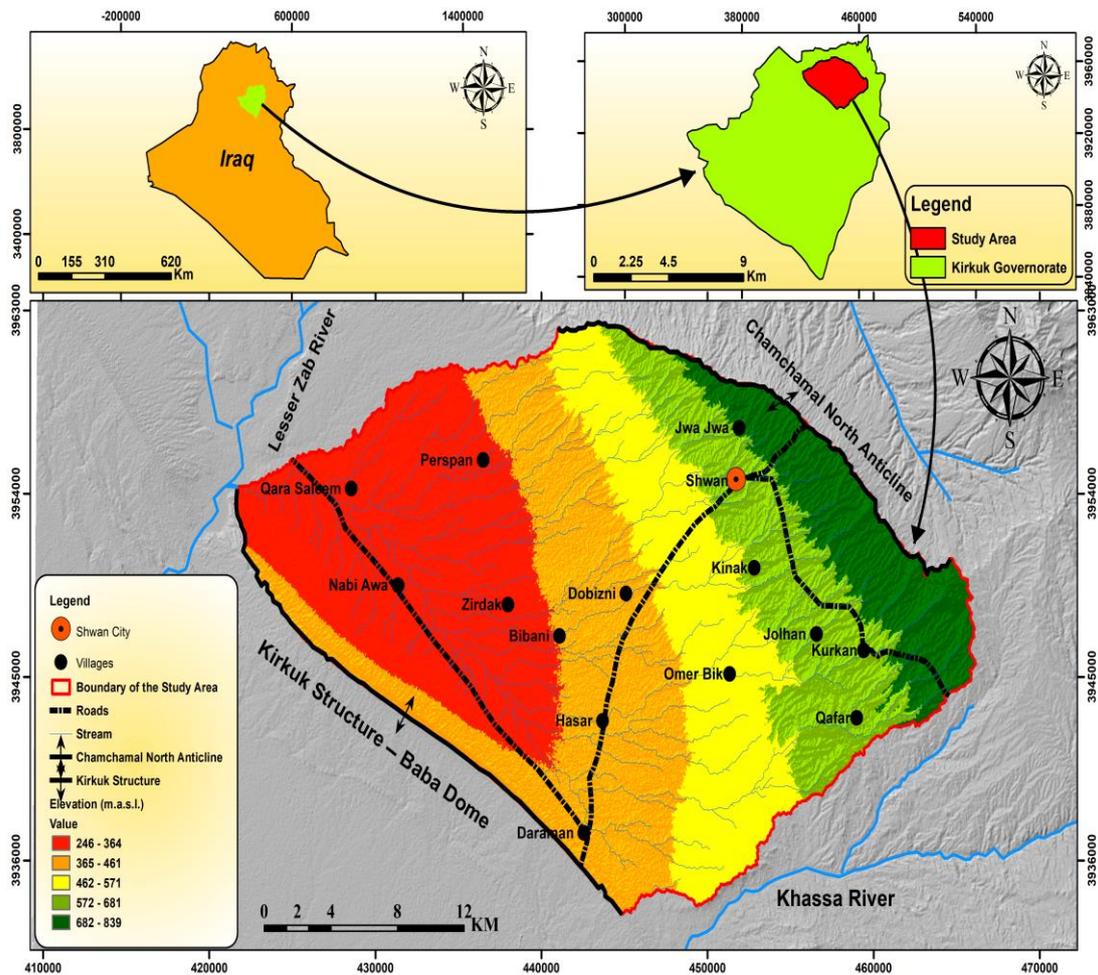


Figure 1- Location and elevation map of the study area.

Geological setting

From the geological points of view, the area is situated within the unstable range, specifically in the mountain range [17]. The formations of the Pleistocene to Holocene ages which are represented by Bai-Hassan Formation and the Quaternary deposit are the dominant units exposed in, and surrounding, the basin [18]. The Quaternary deposits in the area of study are separated into Polygenetic and Slope deposits. The area is bordered by Kirkuk structure and Baba Dome from the southwest, Alkassa River from the west, and the Chamchal North anticline from the northeast, as shown in Figure (2).

Hydrogeological setting

The formations (Bai-Hassan and the Quaternary deposit) are the groups that contain the groundwater aquifers in the study area [18]. The depths of the 55 wells were measured by using GIS program to create the groundwater flow map of the study area, which shows that the water in the area heads mainly from the eastern towards the western directions, as illustrated in Figure (3).

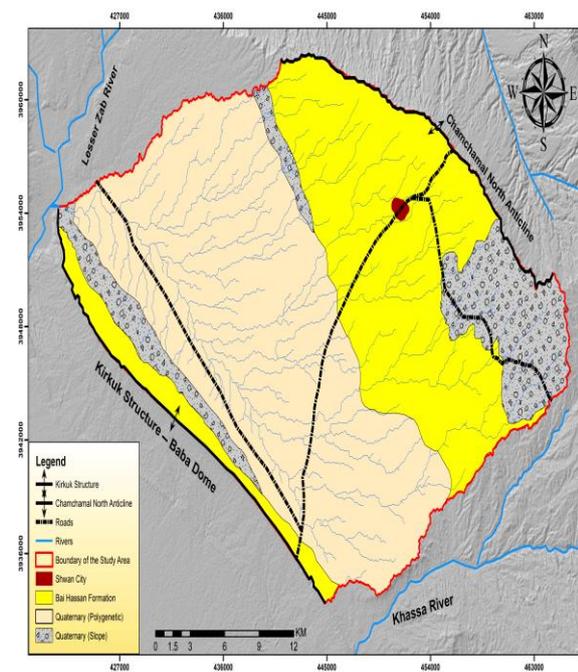


Figure 2- Geological map Of the study area

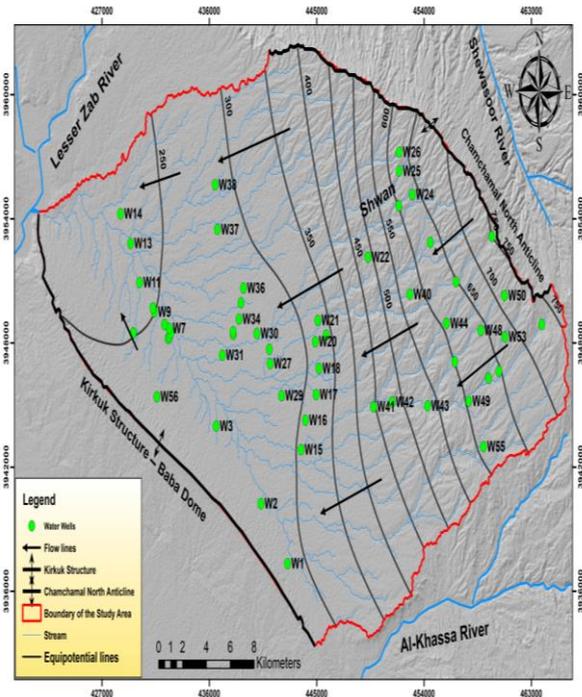


Figure 3- Groundwater flow map Of the study area

Materials and methods

The DRASTIC method is one of the most important and common tools which was developed by EPA (US Environmental Protection Agency) [12] for the purpose of assessing vulnerability in groundwater aquifer. It was subsequently applied by many researchers in many countries who modified it to meet a wide range of different applications, including aquifer thickness, land use, lineaments, and the impact of contaminants [19].

The DRASTIC terminology is the abbreviation of seven parameters, where D=Depth to groundwater, R= Net recharge, A= Aquifer media, S= Soil media, T= Topography, I= Impact of vadose zone, and C= Hydraulic conductivity, as shown in Figure 4. The DRASTIC technique was originally derived from the rating and weights associated with the 7 parameters. The seven parameters are divided into a rating that starts from 1 "lowest polluted" to 10 "highest polluted", as demonstrated in Table (1). Also, each parameter has weights which are explained in Table (2). Parameters with ratings and weights were used to calculate the DRASTIC Vulnerability Index (DVI), as follows:

$$DVI = Dr \times Dw + Rr \times Rw + Ar \times Aw + Sr \times Sw + Tr \times Tr + Ir \times Iw + Cr \times Cw$$

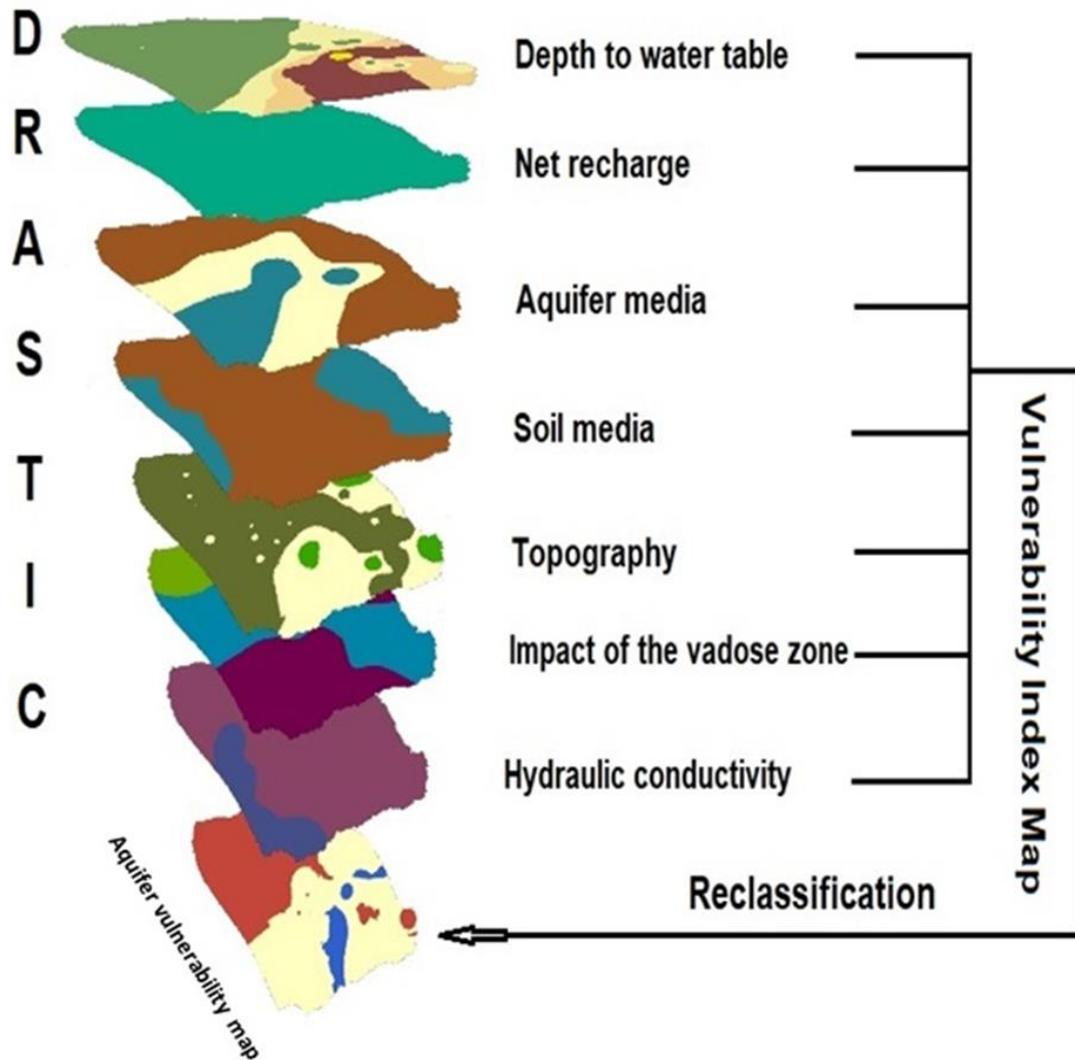


Figure 4- The Methodology flowchart for DRASTIC method

Table 1- Rating of the parameters

Factor	Range	Rating
Depth to water (m)	0 – 1.5	10
	1.5 – 4.5	9
	4.5 – 9	7
	9 – 15	5
	15 – 22	3
	22 – 30	2
	>30	1
Factor	Range(mm/year)	Rating
Net Recharge	Less than 50	1
	50 - 100	3
	100 - 175	6

	175 - 250	8	
	More than 250	9	
Factors	Range	Rating	Typical Rating
Aquifer Media	Massive shale	1 - 3	2
	Metamorphic/ Igneous	2 - 5	3
	Weathered metamorphic/ Igneous	3 - 5	4
	Glacial Till	4 - 6	5
	Bedded sandstone, limestone, shale	5 - 9	6
	Massive sandstone ,massive limestone	4 - 9	6
	Sand and gravel	4 - 9	8
	Basalt	2 - 10	9
	Karst limestone	9 - 10	10
Factors	Range	Rating	
Soil Media	Thin or Absent ,Gravel	10	
	Sand	9	
	Peat	8	
	Shrinking and/or aggregated clay	7	
	Sandy loam	6	
	Loam	5	
	Silty loam	4	
	Clay loam	3	
	Muck	2	
Non shrinking and non-aggregated clay	1		
Factors	Range (percent slope)	Rating	
Topography %	0 - 2	10	
	2 - 6	9	
	6 - 12	5	
	12 - 18	3	
	More than 18	1	
Factors	Range	Rating	Typical Rating
Impact of vadose zone	Confining layer	1	1
	Silt/ clay	2 - 6	3
	Shale	2 - 5	3
	Limestone	2 - 7	6

	Sandstone, Bedded limestone, sandstone, shale, sand and gravel	4 – 8	6
	Metamorphic/ Igneous	2 - 8	4
	Sand and gravel	6 – 9	8
	Basalt	2 - 10	9
	Karst limestone	8 - 10	10
Factors	C (m/day)	Rating	
	Less than 4.0	1	
	4.0 – 12.0	2	
Hydraulic conductivity	12.0 – 30.0	4	
	30.0 – 40.0	6	
	40.0 – 80.0	8	
	More than 80.0	10	

Table 2- Weights of the parameters

Factor	Weights
<i>D: Depth to Water</i>	5
<i>R: Net Recharge</i>	4
<i>A: Aquifer Media</i>	3
<i>S: Soil Media</i>	2
<i>T: Topography</i>	1
<i>I: Impact of the vadose zone</i>	5
<i>C: Hydraulic Conductivity</i>	3

- **Depth to water table (D)**

Depth to water table is an important factor since it represents the time that the pollutant takes to reach the groundwater level after passing through the unsaturated zone. Shallow water has more chance of contamination; the deeper water has less chance of contamination due to longer arrival time [20]. For the current study, the depth of groundwater was calculated in 55 wells distributed inside the basin. The well data was collected by the researcher in September 2019. The values of this parameter varied greatly from one place to another, ranging from few meters to more than 100 meters below the surface. In general, the rating of D parameter began from 1 “low vulnerability” to 9 “high vulnerability” based on Aller *et al.* [12], as shown in Figure 5.

- **Net Recharge (R)**

According to Ersoy *et al.* [21], net charge is the total quantity of water infiltrating from the surface to an aquifer on an annual basis. Recharge of water is the main way to transfer pollutants vertically to the groundwater and horizontally within the aquifer. Precipitation is the dominant source for recharging groundwater in the area of study. The groundwater net recharge was described by a previous work conducted by Mohammed [22]. Based on his results, the total expected average net recharge was estimated at 62.82 mm/year or 19.37% from the total annual precipitation. Accordingly, the recharge value falls within the rating 3 developed by Aller [12] (Figure 6).

• **Aquifer media (A)**

The aquifer medium exerts the major control over the way and path length that a contaminant should follow. The course length is an important control, along with permeability and gradient, in the identification of the time available for attenuation processes like sorption, reactivity, and dispersion, in addition to the extension of the effective surface area of materials contacted in the aquifer [12]. The main aquifer in the Shwan sub-basin is represented by the formation of Bai- Hassan and the Quaternary deposits. The saturated thickness of the aquifer was obtained from the drilling records of the Water Drilling Department in Kirkuk Governorate. The thickness of the aquifer in the basin ranges from 34 m in the village of Hassar to 86 m in the village of Kinak. The aquifer is mainly composed of sand, gravel, and silt. The northern and eastern parts of the basin are ratified with 7 because this part is the least exposed to pollution. While the southern part has the highest pollution with the rating of 9, and the middle part has the average rating value of 8, as demonstrated in Figure (7).

• **Soil media (S)**

Soil media refers to the uppermost part of the unsaturated zone. Generally, the soil is the upper weathered zone of the earth. The soil has a remarkable effect on the amount of recharge which can seep through the earth, hence on the capacity of a pollutant to move vertically in the unsaturated zone. In the current study, the soil map for the study area was prepared from the map previously constructed by the Harmonized World Soil Database (HWSD) [23]. The soil map was reclassified to accommodate the classification of the new DRASTIC system. The north-eastern and south-western parts of the basin had a rating of 6 because they fall within the loam range, while the remaining of the basin falls in the rating of 5 because it is situated within the sandy loam, according to Aller [12], (Figure 8).

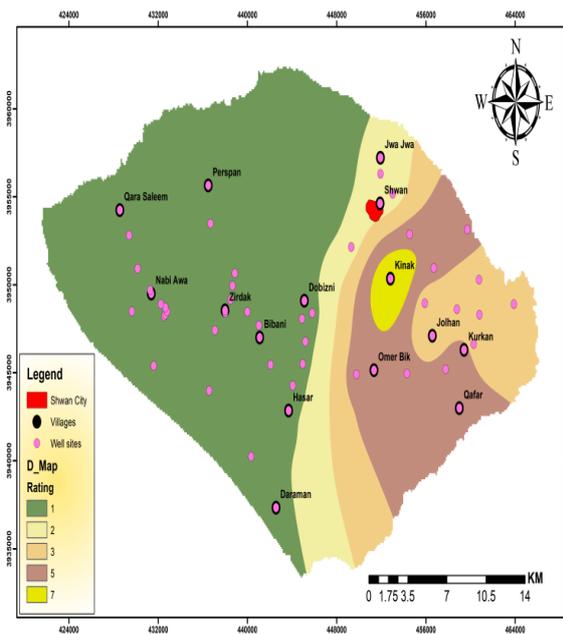


Figure 5- Rating map of depth to groundwater

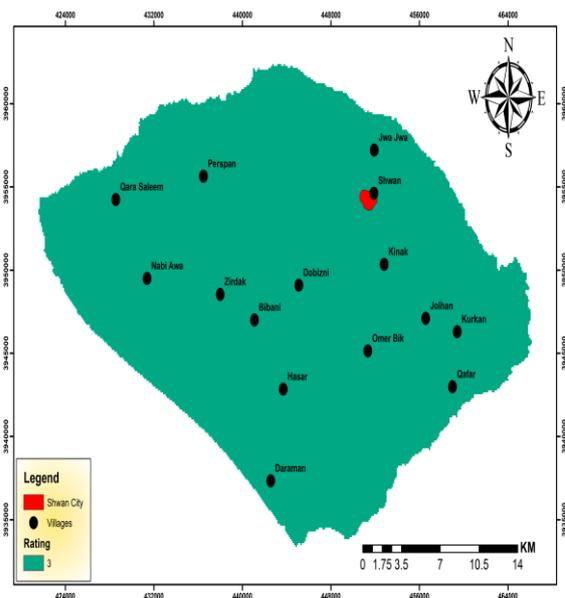


Figure 6- Rating map of net recharge

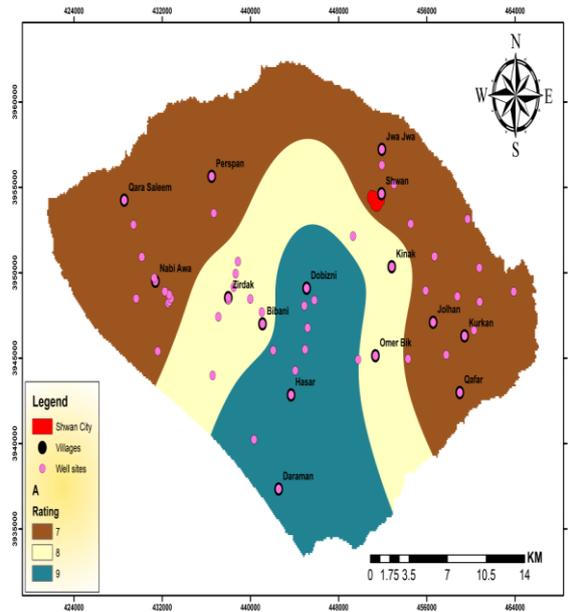


Figure 7- Rating map of aquifer media

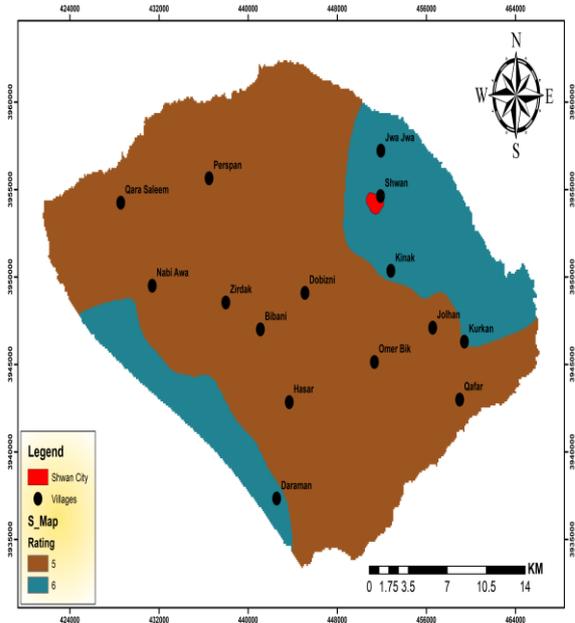


Figure 8- Rating map of soil media

- **Topography (T)**

Topography helps in controlling the probability that the contaminant either remains in one area for a long enough time to infiltrate into the ground or runoff to another area. If the slope is less than 2%, the probability of the pollutant to filter into the ground is large because it reduces the amount of surface runoff that exits from the area. If the slope exceeds more than 18%, the probability of pollution decreases due to increased runoff and less filtering [12]. The topography map of the area was prepared through DEM (Digital Elevation Modeling) from NASA with a resolution of 30m. The slope ranges were extracted from the DEM by the GIS analysis toolbox. The rating values of the topography for most parts of the study area ranged between 9 and 10. In addition, small parts that fall within the regression area had a rating value of 5, as shown in Figure (9).

- **Vadose zone impact (I)**

The material attenuation properties of the area above the water table depend on the type of vadose media. The media of the vadose zone controls the length of the path that the pollutant takes before arriving at the water table, thereby affecting the time obtainable for attenuation [12]. In the current study, the rating values for this parameter were determined based on the drilling and profile of well data collected from the Ministry of Water Resources - Wells Drilling Department in Kirkuk Governorate. Based on this archive, the most vulnerable area is located in the western part of the basin. It entirely consists of gravel and therefore rated with 8. In contrast, the least vulnerable area is located in the northern and central parts of the basin (ratings are 4 and 5, respectively). The other parts of the basin had a rating of 7 due to the fact that they consist mainly of sand and gravel with a less content of silt and clay, as demonstrated in Figure (10).

- **Hydraulic conductivity (C)**

This parameter refers to the capacity of the aquifer to transfer water. It also controls the average of the groundwater flow under a given hydraulic gradient. The value of hydraulic conductivity corresponds to the value of the impact of pollutants [24]. Pumping tests, well sketches, and their data were used for the purpose of the assessment of the hydraulic conductivity in the area of interest. Based on the data recorded from 15 drilled water wells, the value of hydraulic conductivity was calculated using the equation:

$$K = T / b;$$

where K is the hydraulic conductivity (m/day), T is the transmissivity (m^2/day), and b is the saturated thickness (m). The hydraulic conductivity ranges for the Shwan sub-basin were reclassified based on the table prepared by Aller [12]. A total number of 6 pumping tests were conducted for the main formations in the area (Bai-Hassan and the Quaternary deposit), while the remaining pumping well

data were taken from the previously conducted test by Al-Sudani [25]. Accordingly, the values of the hydraulic conductivity for (Bai-Hassan and the Quaternary deposit) ranged 7.31-30 m/day with rating values of 2 and 4. The southern and south western parts of the basin fell within the rating of 2, while the rest of the basin parts fell into the rating of 4, as shown in Figure (11).

Vulnerability map of the study area

The vulnerability map of the Shwan sub-basin was prepared based on the seven parameters (water depth, net recharge, aquifer media, soil media, topography, impact vadose zone, hydraulic conductivity). Seven layers of these parameters were created based on the obtained data from the 55 wells surveyed by the researchers, whereas the archived records were obtained from governmental institutions and some international organizations. These data were treated by using GIS software to produce the seven layers. The final map was created according to the seven layers and reclassified based on Aller [12]. The vulnerability map shows 44.9% of the area is a very low- vulnerable zone, whereas 49.7% has a low and 5.4% a medium-vulnerability, as described in Table (3). The results reveal that the DRASTIC values have a range of 89 - 133. The zonings with very low vulnerability class are located mainly in the western and north-western parts, in addition to small patches in the eastern part of the basin (Figure 12). In contrast, the area with a medium vulnerability zoning occupies a small part of the basin that is located in the south-eastern and eastern parts of the area. The rest of the basin can be classified, however, as having a low pollution, with values having a range of 100-125.

Table 3- Ranges of vulnerability using the DRASTIC model based on Aller *et al.* [12]

Index of vulnerability	Vulnerability degree	Percentage Area %
Less than 100	Very low	44.9
100 – 125	Low	49.7
125 – 150	Medium	5.4
150 – 200	High	0
More than 200	Very High	0

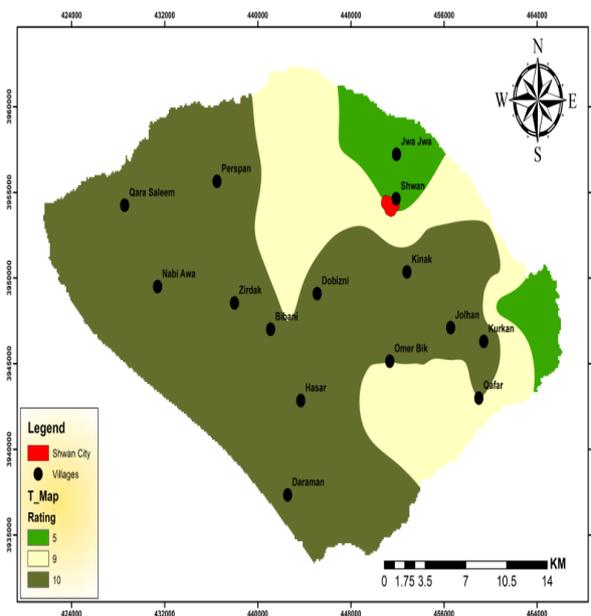


Figure 9- Rating map of topography

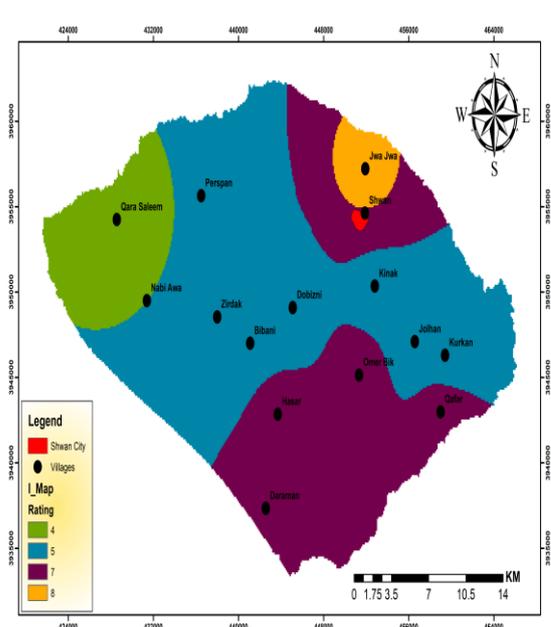


Figure 10- Rating map of impact vadose zone

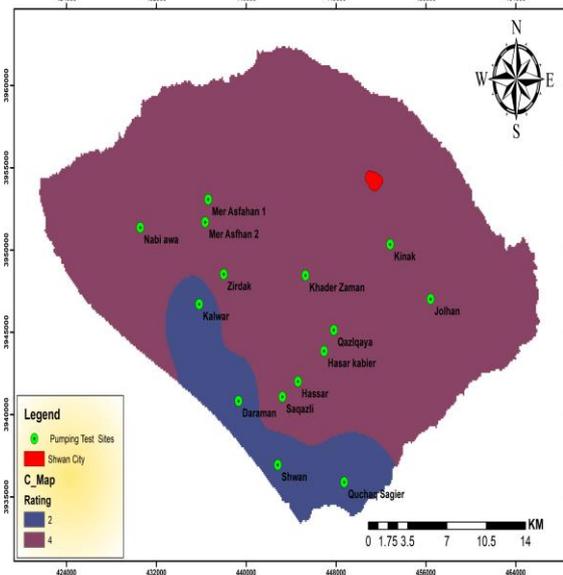


Figure 11- Rating map of hydraulic conductivity Shwan Area

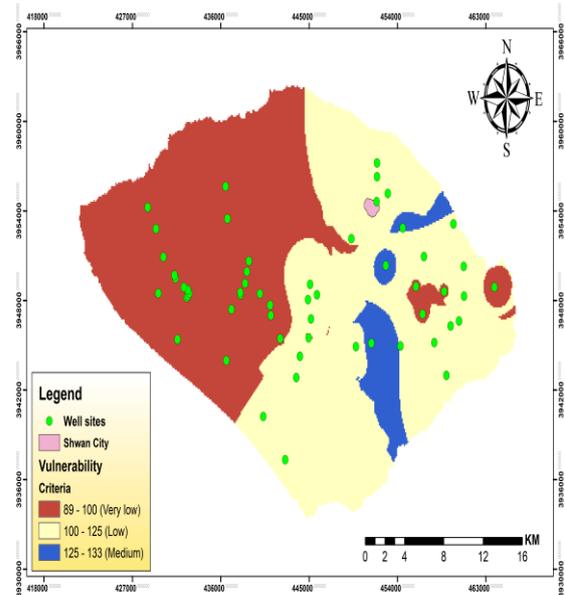


Figure 12- Groundwater vulnerability map of

Conclusions

The present study aimed to use the DRASTIC model for mapping the vulnerability of groundwater in Shwan sub-basin.

Generally, the results show that the range of vulnerability is low in most areas of the basin. The reason for the low DRASTIC range within the area may be the great depth of the groundwater in most parts of the basin, lack of recharge to groundwater, in addition to the confined aquifer condition for most parts of the basin. Through the results obtained, most parts of the basin can be used naturally for agricultural and industrial purposes, except some areas in the south-eastern and eastern parts. These parts must be developed before their usage for such purposes because of their moderate values of vulnerability, which can cause pollution to groundwater if used excessively without treatment. Vulnerability maps of the area can provide valuable bases for groundwater management and land-use planning.

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