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Assessment of Groundwater Pollution Using GIS Based on the DRASTIC Model in Part of the Oued Souf Region (Northeast Algerian Sahara)

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Abstract

This study uses the Geographic Information Systems (GIS)-based DRASTIC model to evaluate groundwater vulnerability in the Oued Souf region of the desert in northern Algeria. By analyzing contamination risks using seven crucial characteristics that affect and regulate the flow of pollutants from the surface to the subsurface, the DRASTIC model is used to create a map of groundwater vulnerability. These factors include topography, hydraulic conductivity, vadose zone influence, groundwater depth, net recharge, and groundwater and soil media each parameter is given a classification and weight, and the DRASTIC Index (DI) is computed by adding together the weights and classifications. According to the findings, around 30% of the research region is categorized as having high susceptibility and 70% as having low vulnerability. The application of GIS-based DRASTIC mapping techniques helps with environmental preservation and sustainable resource management by offering insightful information about groundwater susceptibility. The results emphasize how crucial it is to comprehend possible hazards and the necessity of efficient management techniques in order to protect pure groundwater resources.

Keywords: Groundwater quality; contamination; Vulnerability; DRASTIC; Geographic Information Systems (GIS).

1. Introduction

Only in the dry and semi-arid regions of many nations is groundwater the primary source of water supply for various purposes [1]. However, excessive groundwater use can have a number of negative effects on the environment, such as groundwater contamination, land subsidence, drought during dry spells, and the depletion of groundwater supplies [4, 5]. In the Algerian Sahara, groundwater is the sole resource available to meet the population's diverse needs, including domestic, agricultural, and industrial use [6, 7]. However, these resources are vulnerable to contamination from both anthropogenic and natural factors [8, 9]. Of all the countries, Algeria has the greatest degree of vulnerability [10, 11]. The Oued Souf region has witnessed a remarkable agricultural transformation in the last twenty years, with the cultivated area increasing from 200 hectares in 1993 to more than 50 square kilometers today. This economic boom is largely driven by abundant water resources, but it has also resulted in adverse effects on the environment and the aquifer [12, 13]. Environmental concerns related to groundwater often focus on the effects of pollution and the degradation of water quality for human use. In many areas, groundwater pollution is linked to rapid population growth, unregulated urban development, industrial activities, and insufficient sewage infrastructure. Additionally, the use of pesticides and fertilizers in agriculture frequently contributes to groundwater contamination [14, 15]. Unlike surface water, groundwater pollution is more challenging to detect and manage, and its effects can persist for many years [16, 17, 18]. Groundwater is a valuable, sustainable resource that is generally less vulnerable than surface water resources [19, 20]. Groundwater vulnerability assessment can be categorized into intrinsic, specific, and integrated types. Intrinsic vulnerability refers to the susceptibility based on the geological and hydrogeological characteristics of an aquifer, while specific vulnerability addresses the risk associated with particular pollutants. Both types are crucial for protecting groundwater resources and ensuring water quality from contamination [21, 22, 23]. Vulnerability studies for groundwater aquifers are therefore necessary to identify areas that are at risk of contamination and to develop appropriate management strategies [24, 25, 9]. There are various overlay and index methods for assessing groundwater vulnerability, including well-known techniques such as DRASTIC [26] ; SINTACS [27] ; GOD [28] ; AVI [29] and PI [30, 31]. The DRASTIC approach is a valuable tool for assessing groundwater vulnerability due to its low cost, simplicity, and use of readily available or estimable data. When integrated with GIS, it produces maps that are easy to interpret and incorporate into the decision-making process [32, 33]. This study aims to evaluate groundwater vulnerability to pollution using the DRASTIC model integrated with Geographic Information Systems (GIS) to identify areas with significant vulnerability to contamination from agricultural, domestic, and industrial sources, in order to develop measures and strategies to protect the water resources.

2. Study area

The research region especially represents a portion of the Oued Souf in the northeastern Algerian desert (southeastern Algeria), which is situated at the northern edge of the Great Oriental Erg. This area, which covers roughly 682 km2, lies between latitudes 33°20' and 33°40' N and longitudes 06°40' and 06°50' E (Figure 1). Continental sand dunes that were created in the recent Quaternary epoch define the region (Figures 2 and 3). The majority of the territory is covered by these deposits, which are mainly made up of fine-grained, homogeneous, and dense sand, this is especially true. Vast plateaus, usually rocky and often covered in Quaternary gypsum deposits, are reached by corridors. pathways that connect the gypsum deposits to the sand dunes.

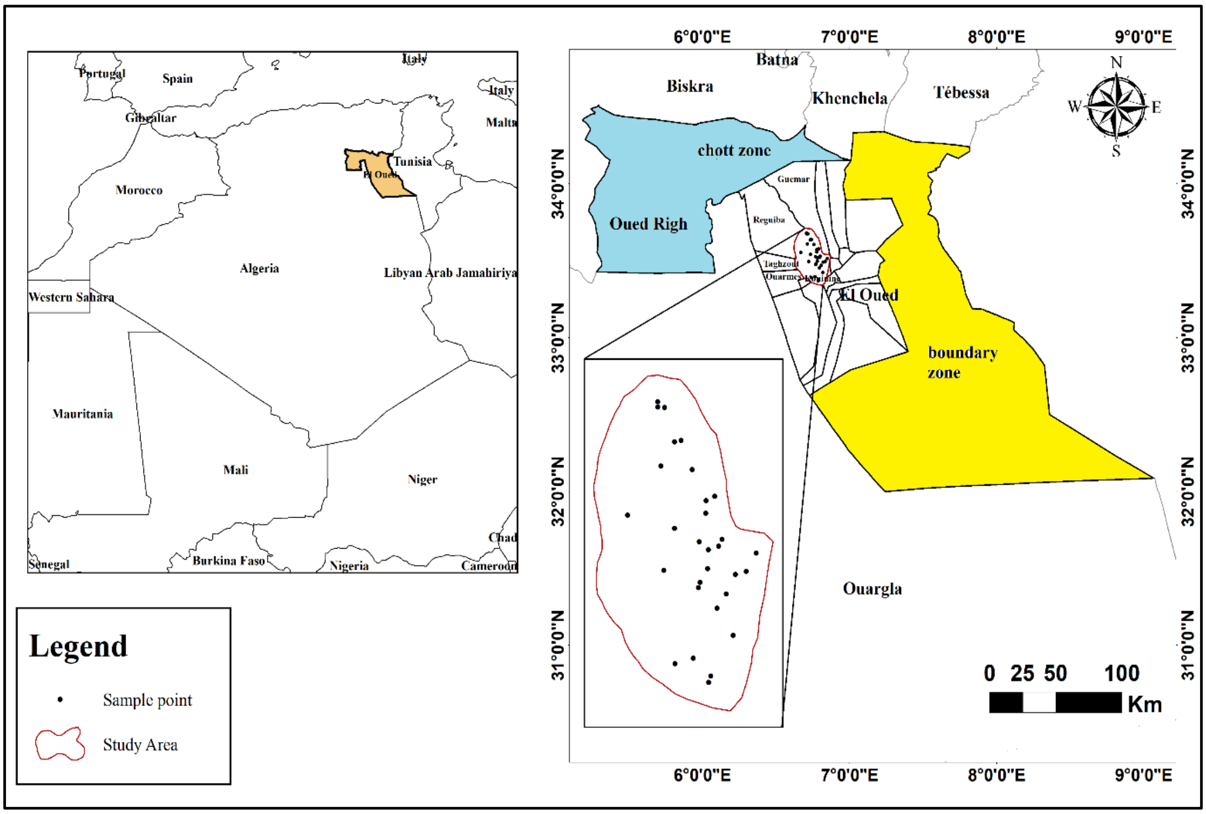


Figure 1: Geographic location of the study area

The lowest portions of the vast Saharan basin in the northern portion of the research region are occupied by saline depressions, or Sebkhas [34, 35, 36, 37, 38]. The region experiences a desert climate, marked by low annual precipitation averaging around 74.68 mm, as reported by the National Meteorological Office in 2022. Temperatures fluctuate significantly, ranging from a low of 5.18°C in January to a high of 40.77°C in July. The climate is characterized by hot, dry summers and mild winters, contributing to the overall aridity of the area. These climatic conditions significantly influence the local ecology and hydrology, limiting water availability and vegetation growth.

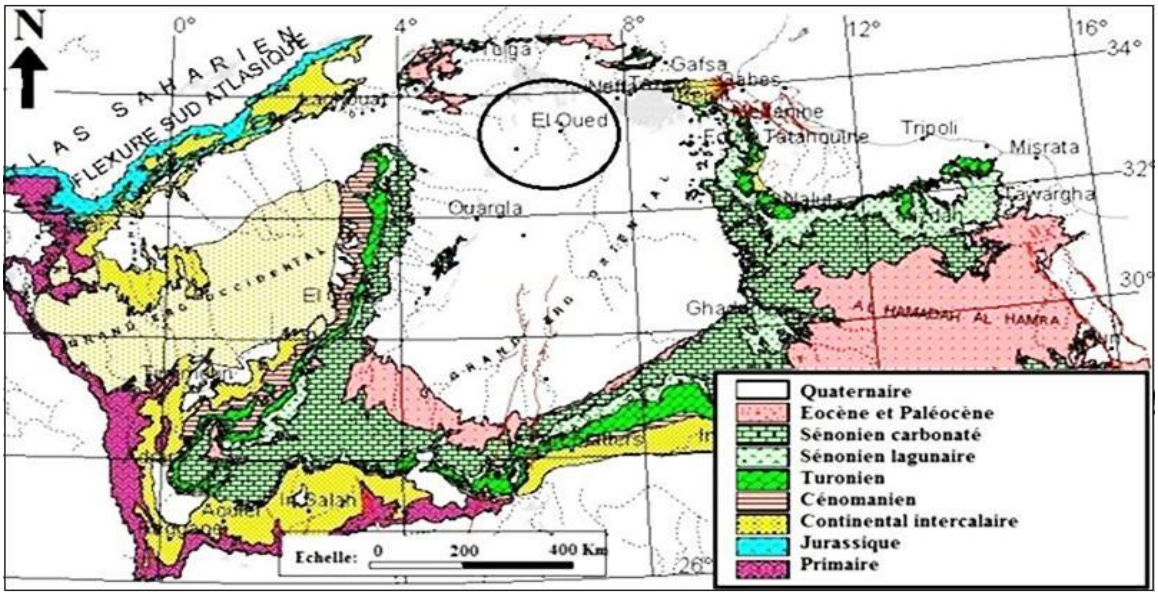


Figure 2: Geological map of the Grand Erg Oriental [39]

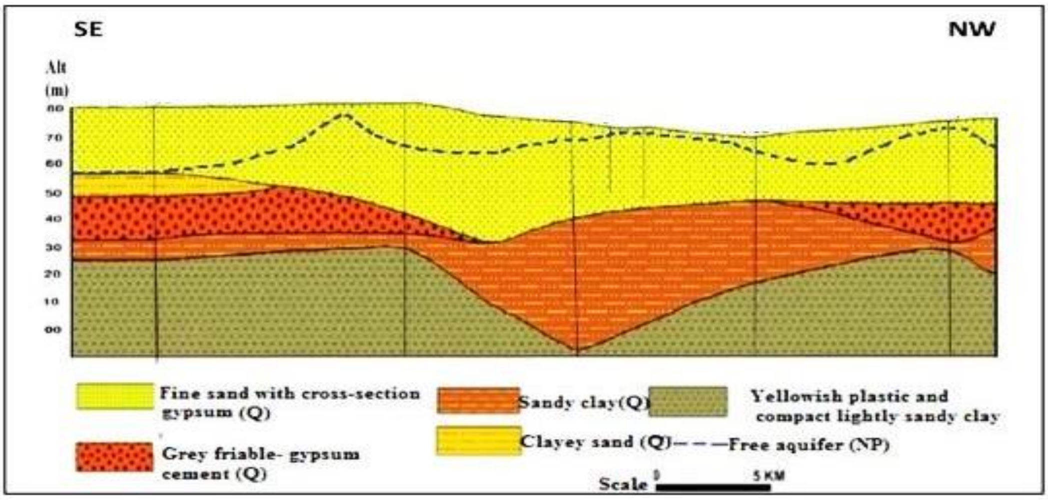


Figure 3: Hydrogeological section (SE-NW) of the study area [13]

3. Materials and Methods

3.1 How the DRASTIC index is calculated?

The DRASTIC model includes seven key factors that assess groundwater vulnerability. These factors are: groundwater depth (D), net recharge of aquifers (R), aquifer media (A), soil type (S), topography (T), zone of influence (I), and hydraulic conductivity of the aquifer (C). Each factor represents a specific hydrogeological condition that affects the overall vulnerability of groundwater [40, 41, 42, 43]. These parameters were rated on a scale of 1 to 10 according to available literature. Additionally, each parameter was assigned a weighting ranging from 1 to 5 (Table 1).

$$\mathbf{DRASTIC_{index} = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w} \quad \mathbf{(1)}$$

Where (D) Depth water level, (R) recharge, (A) aquifer media, (S) soil media, (T) topography, (I) impact of the vadose [44, 45, 46].

In the DRASTIC method, (w) represents the specific weight assigned to each parameter, and (r) denotes the rating for that parameter. The vulnerability index is calculated by multiplying the rating of each parameter by its corresponding weight.

3.2 Geographic Information System (GIS)

The capacity of Geographic Information System (GIS)-based methods to combine modeling functions with spatial data has made them popular recently for assessing groundwater vulnerability.

Researchers can create comprehensive vulnerability maps in a GIS context by mapping and superimposing elements that affect vulnerability [47, 48]. The final vulnerability maps for the DRASTIC indices were made using ArcGIS 10.8 in order to evaluate the research area's groundwater's vulnerability to contamination.

Table 1. Ratings given to the parameters of the DRASTIC method and their weighting [49]

Parameter(weights)	Parameter Value/Types	Ranges
D Depth to water (Weight 5)	>30m	1
	30 – 22.5m	2
	22.5 – 15m	3
	9 – 15m	5
	4.5 – 9m	7
	3 – 4.5m	9
	1.5 – 3m	10
R Net recharge (weight 4)	0 – 50mm	1
	50 – 100mm	3
	100 – 175mm	6
	175 – 225mm	8
A Aquifer media (weight 3)	Silt/Clay	1
	Shale	2
	Metamorphic/Igneous	3
	Sand and gravel with significant silt and clay	4
	Shale in sequence	6
	Sandstone	6
	Massive limestone	6
	Sand and gravel	8
	Basalt	9
	Karst limestone	10

S **soil media** **(weight 2)**	Unfissured Clay	1
	Siltyclay	3
	Limon silteux	4
	Silt	5
	Siltysand	6
	Clay, aggregates or slopes	7
	Sand	9
	Gravel	10
	Soil slightly thick or absent	10
T **Topography** **(weight 1)**	>18 %	1
	12 – 18 %	3
	10– 12 %	5
	8 – 10 %	7
	6 – 8 %	8
	2 – 6 %	9
	0 – 2 %	10
I **Impact of** **vadose** **zone** **(weight 5)**	Silt and Clay	1
	Shale	3
	Limestone	6
	Sandstone	6
	Lite limestone, sandstone, shale Sand and gravel	6
	with silt and clay	6
	Sand and gravel	8
	Basalt	9
	Karst limestone	10
C **Hydraulic** **Conductivity** **(weight 3)**	4.7·10-5 – 4.7·10-5 m/s	1
	4.7·10-5 – 14.7·10-5 m/s	2
	14.7·10-5 – 32.9·10-5m/s	4
	32.9·10-5 – 4.7·10-4 m/s	6
	4.7·10-4 – 9.4·10-4 m/s	8

Table 2. DRASTIC vulnerability classes [50, 51].

Vulnerability class	Vulnerability index	Vulnerability index of study area (%)
Low	<100	70
Moderate	101 – 140	30
High	141 – 200	-
Very high	>200	-

4. Results and Discussions

4.1 Vulnerability Parameters

This study looked at seven DRASTIC model-related vulnerability criteria. A Geographic Information System was also used to map these parameters (D. R. A. S. T. I. C.) and their outcomes (GIS 10.8).

4.2 The depth of the water table (D)

One important component of the DRASTIC model is the water table's depth, which is the distance between the ground surface and the water table [52, 53].

The vertical distance between the top of the saturated zone and the ground surface is the aquifer's water table depth. Since the water table serves as a buffer against pollutants, a deeper depth generally lowers the danger of pollution.

On the other hand, contaminants can more readily enter and contaminate groundwater when the water table is shallower. Table 1 shows the three groups into which groundwater level data from 23 agricultural wells in the research region were divided. Figure 4 shows the spatial distribution of these classes.

The image shows that the southern portion of the research area, which is less likely to be impacted by pollution, is where deeper groundwater strata are mostly found. On the other hand, the northern area, which has shallower groundwater, is anticipated to be more susceptible to serious negative consequences.

Table 3. The Weighting of Groundwater Depth Parameters

Depth groundwater level(m)	Classification (m)	Range	Weight
30 – 56.5	>30m	1	5
23.1 – 30	30 – 22.5m	2	5
15.2 – 21.5	22.5 – 15m	3	5

4.3 Recharge net (R)

It is the amount of water that seeps into the water table from various inputs, including rainfall [54, 55, 56]. Low precipitation and high evapotranspiration cause the readily accessible water reserve in the study region to be depleted for a large portion of the year, according to the water balance. Consequently, there is little groundwater recharge [57]. Desert regions and desolate, undeveloped areas are examples of this type. Because of the extremely dry climate, there is very little or no recharge (Figure 5).

Table 4. The Weighting of Rainfall Parameters

Rainfall (mm/year)	Parameter Classification	Range	Weight
0	0 - 50	1	4

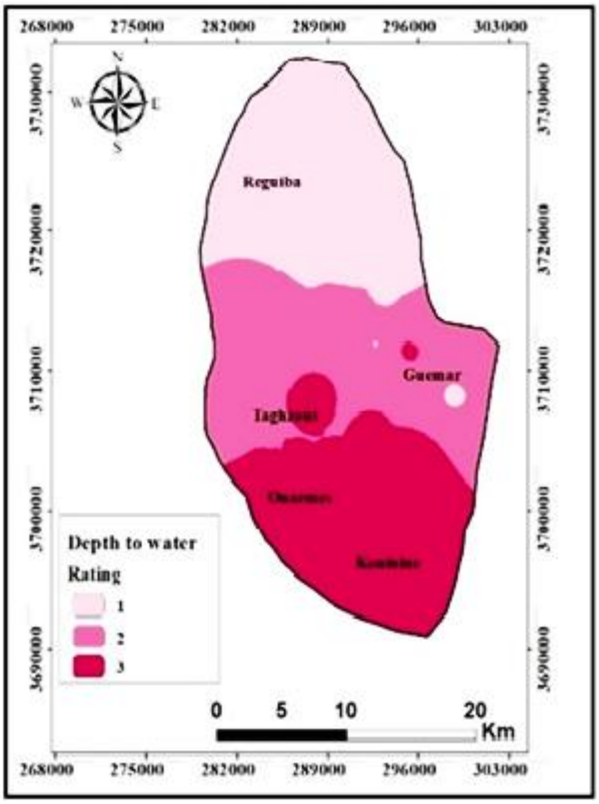


Figure 4: A.Water Depth map

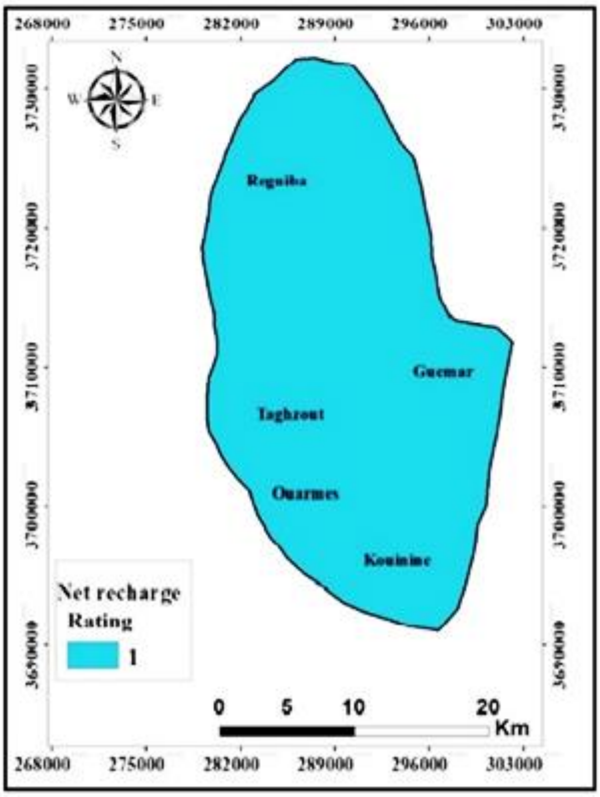


Figure 5: Net Recharge map

4.4 Aquifer media (A)

According to the lithological files currently available for the research region, the majority of the groundwater media and their corresponding categories consist of sand and gravel, with layers of gypsum and limestone also present in the chotts and Sebkhas. This property is related to the amount of water that saturated porous materials can hold [58, 59]. The hydrogeological map produced by the National Agency of Hydraulic Resources has given this categorization a score of 8 (Figure 6).

Table 5. The Weighting of Aquifer Media Parameters

Aquifer Media	Parameter Classification	Range	Weight
Sand	Sand and Gravel	8	3

4.5 Soil media (S)

Soil media is the topmost weathered layer of the unsaturated zone and controls the amount of recharge that can percolate downward [60, 61]. It is the topmost layer of the vadose zone, and its properties are important in determining possible contamination, while deeper soil generally reduces infiltration. In general, a soil map can show the rates of pollutant infiltration. In determining the risks of soil contamination, factors like clay type, grain size, and shrinkage potential are important; in fact, the vulnerability of an aquifer decreases with lower clay content, reduced shrinkage potential, and smaller particle sizes. The soil type identified in the study area is sand (Figure 7).

Table 6. The Weighting of Soil Media Parameters

Soil media	Classification (m)	Range	Weight
Sand	Sand	9	2

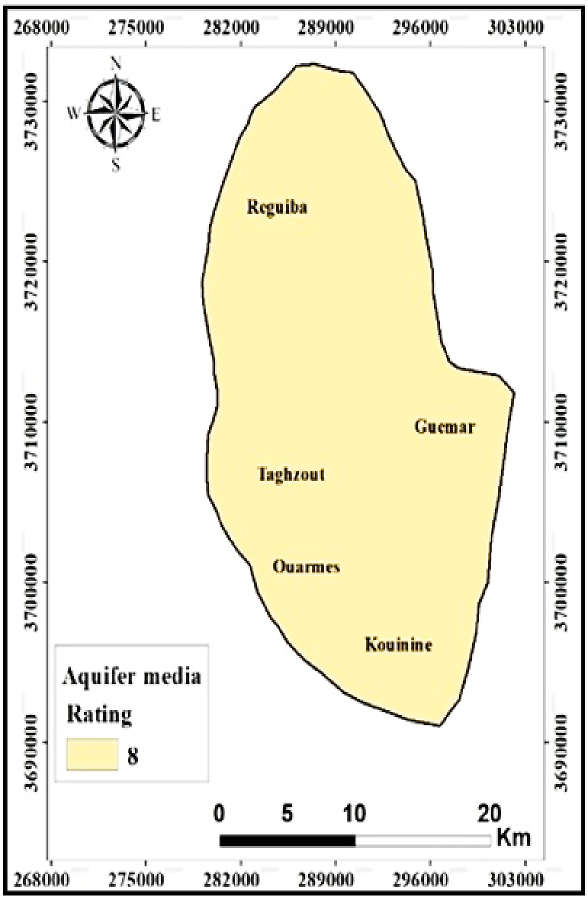


Figure 6: Aquifer media map

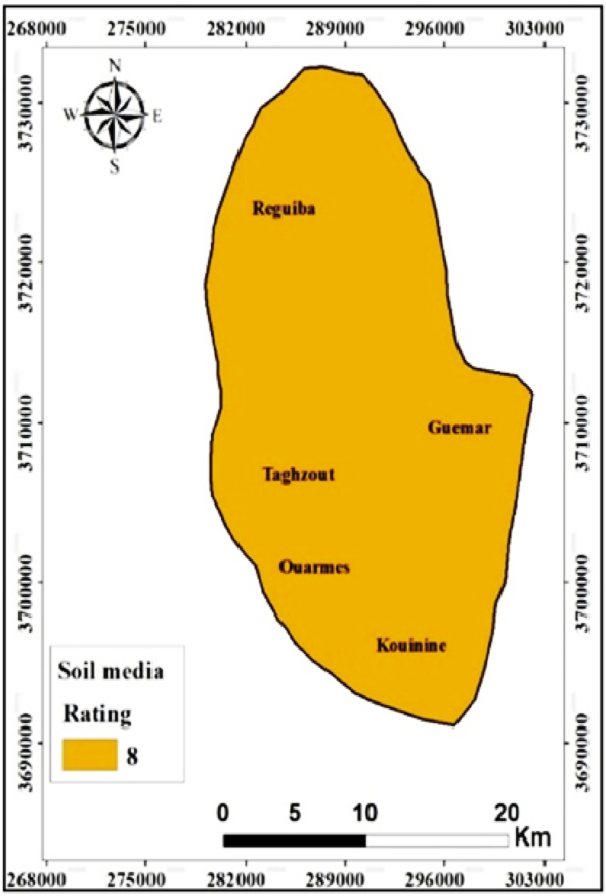


Figure 7: Soil media map

4.6 Topography (T)

It refers to the slope and the availability of slopes in an area. It affects the rate of surface runoff and the time contaminants remain on the ground before entering the saturated zone [62, 63].

The study area in the lower desert is characterized by its flat terrain according to classification table1. The slope map for study area was mapping using the digital elevation model (ASTER-

DEM) in a point file format with a spatial resolution of 30 meters. Areas with low slopes tend to reduce surface runoff capacity, increase the likelihood of infiltration, and heighten the risk of groundwater contamination. This is evident in the map (Figure 8), where the lowest slopes are concentrated in the northern section, making it more sensitive to contamination compared to the southern part of the research region.

Table 7. The Weighting of Topography Parameters

Topography	Classification (m)	Range	Weight
0 – 2 %	0 – 2 %	10	1

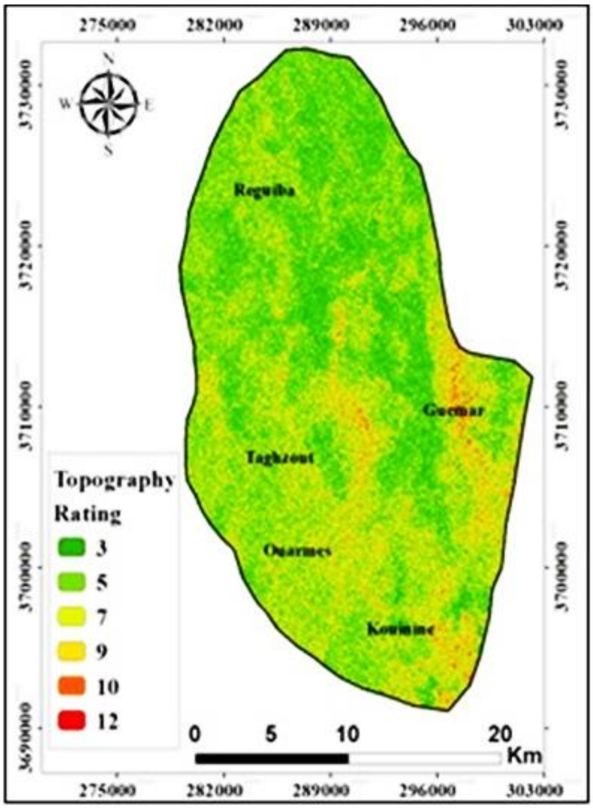


Figure 8: Topography map

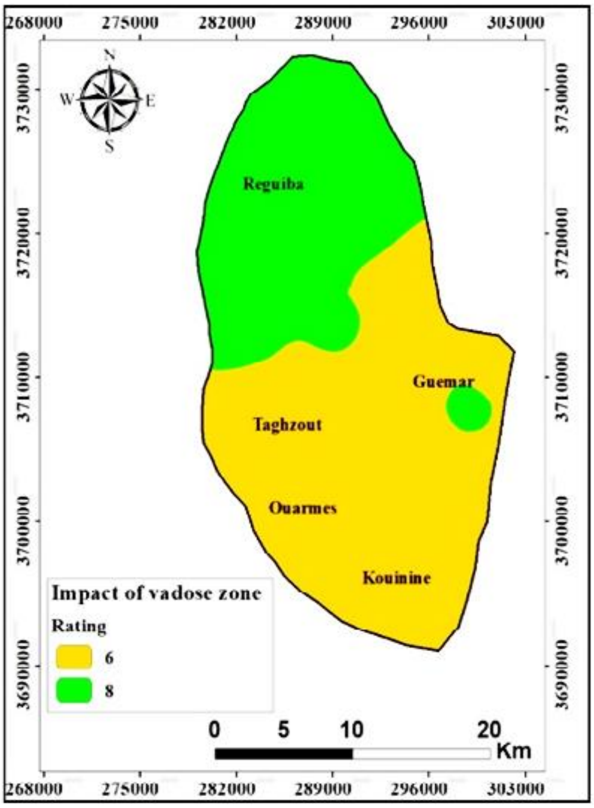


Figure 9 : Vadose zone map

4.7 Impact of Vadose Zone (I)

The unsaturated zone, also known as the vadose zone, is the region between the aquifer and the soil surface and is referred to as the unsaturated zone above the water table [64, 65]. The vertical flow of water in this zone is a major cause of contaminant transport in groundwater, so it is an important consideration when determining groundwater vulnerability. The characteristics of the unsaturated zone can significantly affect the attenuation properties of the media above the water table. Additionally, subsurface geology and lithological information from drilling logs are applied to construct a vadose zone map. Based on the geological cross-sections of the study region and the categorization values (Table 1), sandstone, sand, and gravel were identified (Figure 9).

Table 8. The Weighting of Vadose Zone Parameters

Vadose zone	Classification (m)	Range	Weight
Sandstone	Sandstone	5	6
Sand and Gravel	Sand and Gravel	5	8

4.8 Hydraulic Conductivity (C)

Hydraulic Conductivity indicates how easily water can flow through it. The extent of contamination is influenced by the speed of groundwater movement, which is controlled by hydraulic conductivity. Therefore, groundwater vulnerability is directly related to the hydraulic conductivity of the aquifer [61, 62]. The hydraulic conductivity of an aquifer reflects the capacity of the aquifer media (soil and rock) to transmit water through pore spaces or fractures.

This property is crucial as it influences both the velocity of pollutant migration and their dispersion within the groundwater.

The hydraulic conductivity in the study area was obtained fall within Range 1 (Table 9), suggesting very low hydraulic conductivity (Figure 10).

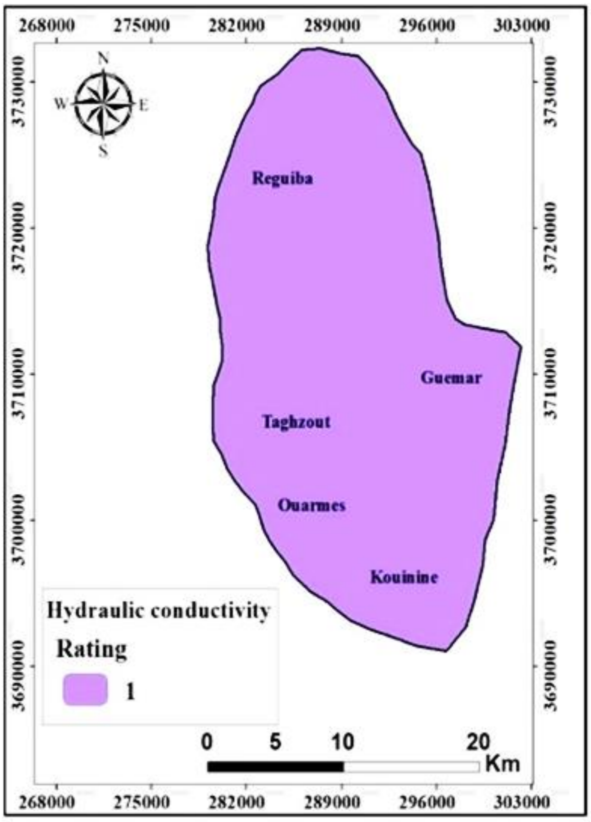
Table 9. The Weighting of Hydraulic Conductivity Parameters

Vadose zone	Classification (m)	Range	Weight
Sandstone	4.7·10-5 – 4.7.10-5 m/s	1	3

4.9 DRASTIC vulnerability index

These parameters were used to construct the vulnerability index, which was then assessed using the DRASTIC method. The research region is classified into two vulnerability groups, as shown by the results, which ranged from 94 to 114 on the DRASTIC index scale (Figure 11):

- The southern half represents low vulnerability (< 100), encompassing roughly 70% of the region;
- The northern section represents moderate vulnerability (101-140), covering 30% approximately of the overall research area.



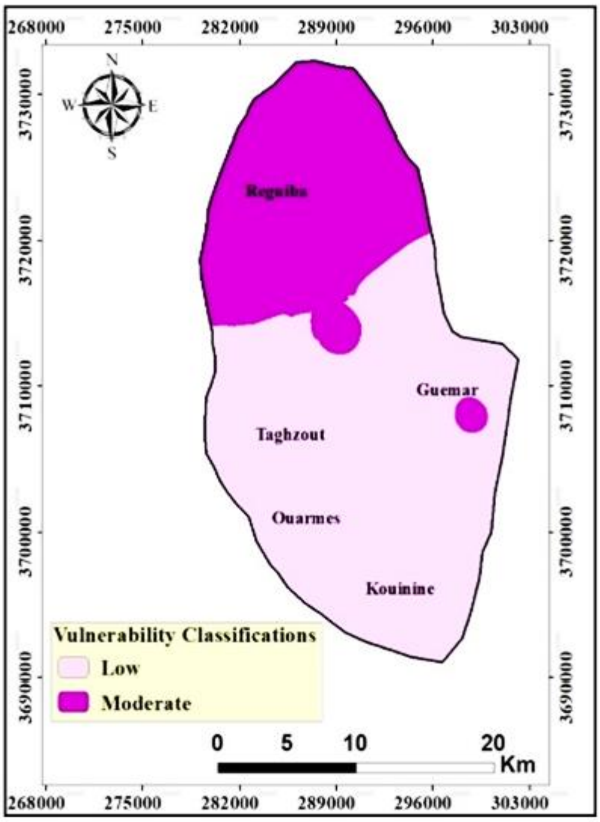


Figure 10: Hydraulic Conductivity map **Figure 11**: Map of DRASTIC vulnerability index

5. Conclusion

In order to manage groundwater resources and establish protection zones, groundwater vulnerability assessments are crucial instruments. In this case, a groundwater vulnerability map for the research area was created using a GIS-based DRASTIC model. To find vulnerable areas, seven distinct hydrogeological input layers were used. The quantile classification approach was used to reclassify the DRASTIC vulnerability index, which varied from 94 to 114, into two groups: low (94–100) and moderate (100–114).

About 70% of the region was categorized as having low to moderate susceptibility, according to the findings of the groundwater vulnerability assessment. The southern, eastern, and western regions of the research area are included in this category. On the other hand, because to its shallow groundwater level and easy slope, almost 30% of the remaining region was categorized as having moderate to high susceptibility. These regions consist of the study area's northern section and a tiny section of its eastern section. Areas with moderate to high susceptibility necessitate careful planning and groundwater monitoring, according to the findings and conclusions. Activities that make groundwater more susceptible to pollution are also included.

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