IRAQI BULLETIN OF GEOLOGY AND MINING (IBGM)
IRAQ GEOLOGICAL SURVEY (GEOSURV-IRAQ)

Vol.19, No1, 2023 ***p 99 – 115***

MAPPING GROUND WATER POTENTIAL RECHARGE ZONES OF WADI Al-BATIN ALLUVIAL FAN, USING REMOTE SENSING AND GIS TECHNIQUES, SOUTHWESTERN IRAQ

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Received: 04/ 09/ 2022, Accepted: 12/ 12/ 2022
Keywords: Groundwater potential recharge (GWPR); Analytical Hierarchy Process (AHP); GIS and RS;
Al-Batin alluvial fan; Iraq

ABSTRACT

Groundwater potential recharge (GWPR) zones are an important process in managing water resources. Six thematic layers were used to produce GWPR mapping for Wadi Al-Batin alluvial fan, Southwestern Iraq with GIS environment and analytical hierarchical process (AHP), including geology, lineaments density, slope gradient, drainage density, soil, and slope aspect. Based on the importance, the thematic layers are ranked, which control the GWPR. Drainage density, lineament density, slope aspect, and slope gradient maps are classified into five classes, whereas, geology and soil are classified into six classes. The classes are weighted based on the magnitude of groundwater recharge potential. The AHP technique divides the entire into three zones based on GWPR values: high, moderate, and low. The final GWPR map demonstrated that the western and northwestern parts of the alluvial fan have greater groundwater recharge potentials with 70% of the total area due to the increase in the infiltration rates as a result of the gravely and sandy soils besides the agricultural land use in the present areas. However, the other part of the fan ranged between moderate and low with 25% and 5% of the total area, indicating suitable zones for groundwater artificial recharge processes.

INTRODUCTION

Subsurface water is a vital source of the natural water cycle, which is stored beneath the water table in the pore spaces of soil and rock (Fitts, 2002). Its availability provides a valuable resource for residential, agricultural, and socioeconomic development operations (Ayazi *et al*., 2010) Alluvial fans are conical fan-shaped slopes that start at steep mountain drainage outlets and end in low-relief basins with little stream intensity. The cone-shaped deposit appears to be fan-shaped. In certain spots, stream channels have been carved out of the alluvial fan material. In contrast to alluvial plains, alluvial fans have a distributary fluvial system, whereas plains have a through-flowing system (Al-Sahlani, 2020).

The Wadi Al-Batin alluvial fan is regarded as the primary source of groundwater water for southern governorates, such as Basra and Samawah. Many authors have researched it, including Maala (2009), who identified four stages of the fan. Al-Batin alluvial fan was defined by Sissakian and Abdul Jab'bar (2014) as a "multistage, huge fan encased in gypcrete”. Al-Kinani and Merkel (2017) described the groundwater of the Al-Batin alluvial fan aquifer using hydrochemical and isotopic analysis. Whereas Abd Al Karim (2009) stated

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that the Wadi Al-Batin fan was formed during the Pleistocene era's rainy period and mentioned a number of dry valleys that cut through its surface.

Groundwater is the primary supply of water for a variety of purposes, Groundwater recharge zone (GWRZ) mapping has been defined as a tool for the methodical development and planning of water resources (Elbeih, 2015). The analytical hierarchy process (AHP) is the most extensively utilized approach for establishing GWRP zones and environmental management. Using this method, specialists can see how important thematic layers are when analyzing GWRP (Ahmed and Sajjad, 2019). Groundwater potential areas have been defined using a variety of datasets, including maps (i.e., geological, lithology, geomorphology, and soil), digital elevation model (DEM), and the Landsat 8 satellite.

The main objective of delineation of the groundwater potential recharge zone of the study region in order to ensure that groundwater resources are developed and managed in the most efficient and sustainable way possible.

STUDY AREA LOCATION

The Al-Batin alluvial fan is one of the most significant fans in Iraq, it is start extending from the Iraq-Kuwait border in the northeast to its origin 700 kilometers southwest, in Saudi Arabia, where it is known as Wadi al-Rimah (Sissakian and Fouad, 2012). It is the main geomorphological unit in the southwestern area, mainly within Basrah Governorate, south of Iraq between latitude (30º 23′ – 30º 51′) N and longitude (46º 43′ – 47º 15′) E). The fan represents the southern and northern limits of the Iraqi and Kuwait international borders, respectively (Sissakian *et al*., 2011), has an area of about (22384 Km^2), and the elevation of the study area is range from 0 to 313 m above the sea level (Figure 1).

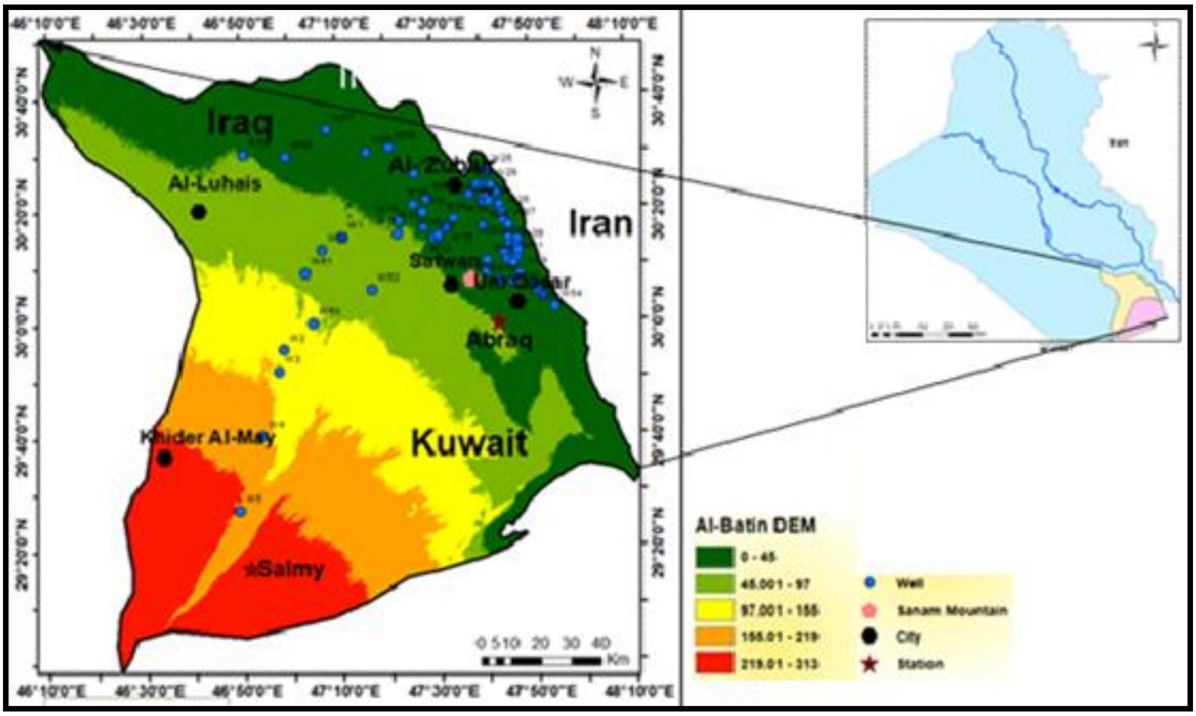


Figure 1: location map of the study area.

TECTONIC AND HYDROGEOLOGICAL SETTING

Tectonically, the southern desert is a portion of the stable shelf of the Arabian platform within the Mesopotamian zone, Zubair subzone (Jassim and Guff, 2006). The Takhadid Al-Qurna Fault passes through the fan in the north. The subzone's southern border is either at Al-Batin Fault or along a Transversal fault in Kuwait. It is characterized by block tectonics and the absence of tectonic folds, as well as a flat nature due to almost level beds, with a regional dip toward the east and northeast (Figure 2).

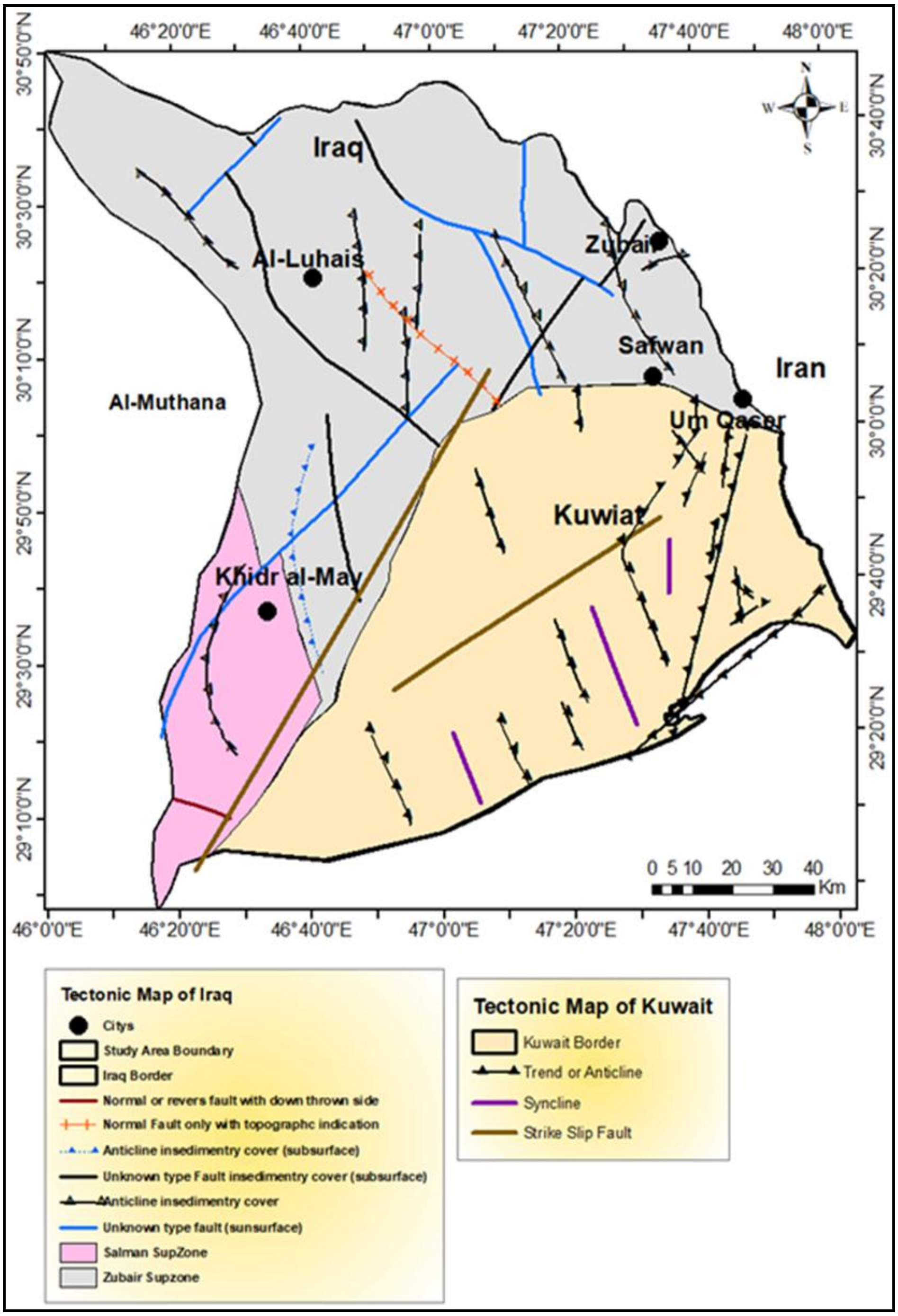


Figure 2: Tectonic map of the Wadi Al-Batin alluvial fan transboundary (Jassim and Guff, 2006).

Hydrogeological, water requirement in Kuwait is covered by the Dibdibba regional aquifer, which stretches through Saudi Arabia. As sharing countries to the regional aquifer, Kuwait, Saudi Arabia, and Iraq rely heavily on groundwater from the Dibdibba trans boundary Aquifer. The population of Saudi Arabia and Iraq is constantly growing. Because of the rise of irrigated agriculture and industrial activity in the three nations that share the aquifer, the pressure on brackish groundwater resources has increased dramatically in recent decades. As a result, it is necessary to rely on groundwater resources and determine the extent to which they can help meet agricultural and industrial water demands (Jassim and Guff, 2006) (Figure 3).

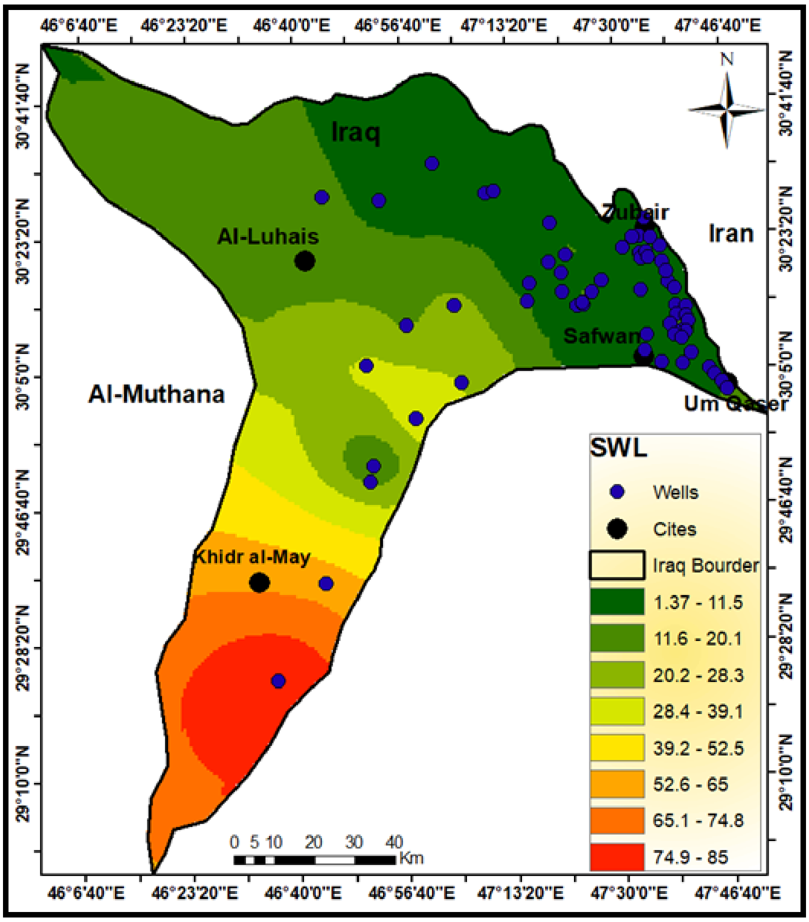


Figure 3: Hydrogeological map of the Wadi Al-Batin area (Jassim and Goff, 2006).

METHODOLOGY AND MATERIALS

To design the groundwater potential recharge map of the Wadi Al-Batin alluvial fan, a different source of the parametric dataset was used including the DEM with a resolution of 15 m and other ancillary data sources. The geological layer is a scale from a geological map of Iraq (Jassim and Guff, 2006; Sissakian and Fouad, 2012), soil layer by soil map of Iraq (Jassim and Guff, 2006). Remote sensing data, including slope gradient, drainage density, lineaments, and slope aspect map from the DEM).

ArcGIS 10.6 was used to create thematic maps of lineament density, drainage density, slope gradient, and slope aspect, while Landsat 8 resolution 30 m was used to create the thematic layers. The geological source of the Wadi Al-Batin alluvial fan was identified using a geological map with a scale of 1: 250 000. The chart of soil types is based on the soil maps of Iraq and Kuwait. For each input item, a thematic map is constructed utilizing a variety of sources, such as geology maps, water well records, and satellite pictures. The input layers are listed in order of importance.

A result of a finite combination of significant factors, such as geology, topography, soil, slope aspect, slope gradient, drainage pattern, geomorphology, and others, results in an integrated dynamic system that influences groundwater occurrence and distribution (Arkoprovo *et al*., 2012). The GWPR procedure is shown in Figure 4.

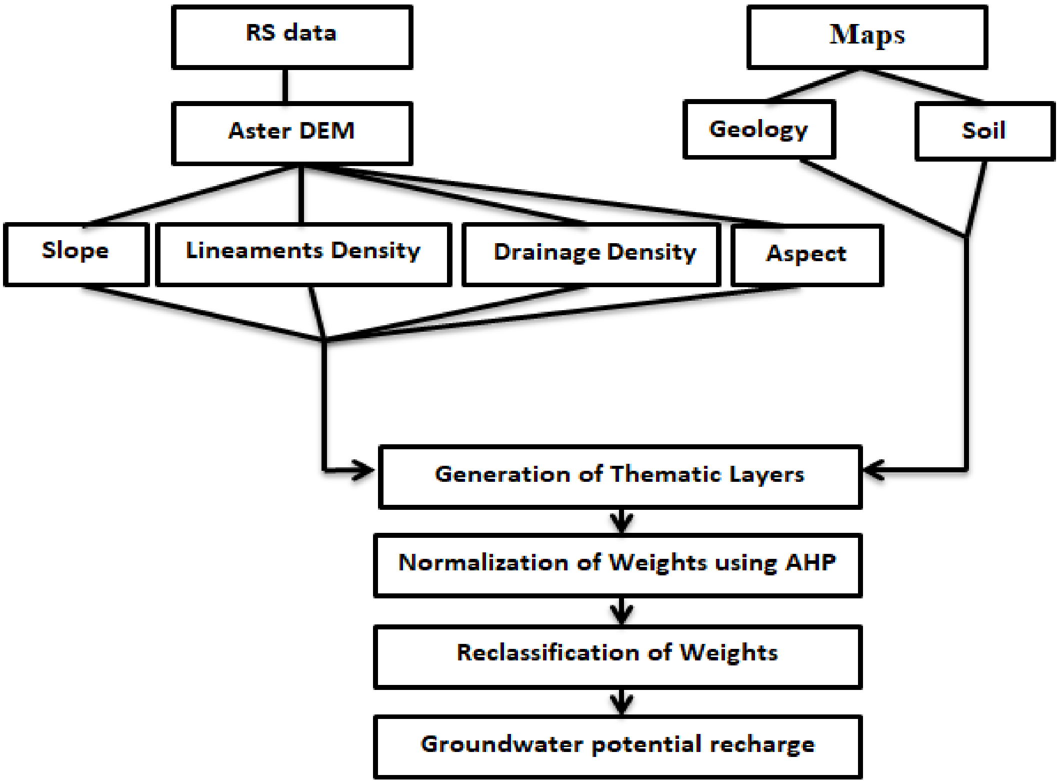


Figure 4: Groundwater potential recharge procedure steps.

GROUNDWATER POTENTIAL RECHARGE (GWPR) MAP

To estimate the GWPR index, a combination of the weighted linear technique and equation (1) is used to allocate weight to each element (Malczewski, 1999). GWPR mapping is done using a variety of thematic layers. The number and types of thematic layers were varying from one study to another according to the amount of data in the area under interest.

The AHP provides cost-effective, straightforward, and logical output for multi-parameter situations (Saaty, 1980) (Table 1, 2, 3, 4, and 5).

Table 1: criteria weight.

criteria	geology	soil	lineaments	slope	drainage	Aspect	Criteria weight WC
geology	1	2	3	4	5	6	0.4
soil	0.5	1	1.5	2	2.5	3	0.2
lineaments	0.33	0.66	1	1.3	1.6	2	0.13
slope	0.25	0.5	0.75	1	1.25	1.5	0.1
drainage	0.2	0.4	0.6	0.8	1	1.2	0.08
Aspect	0.16	0.33	0.5	0.66	0.71	1	0.07

Table 2: normalize the pairwise matrix.

criteria	geology	soil	lineaments	slope	drainage	Aspect
geology	0.4	0.4	0.39	0.4	0.4	0.36
soil	0.2	0.2	0.195	0.2	0.2	0.18
lineaments	0.132	0.132	0.13	0.13	0.128	0.12
slope	0.1	0.1	0.0975	0.1	0.1	0.09
drainage	0.08	0.08	0.078	0.08	0.08	0.072
Aspect	0.064	0.066	0.065	0.066	0.0568	0.06

Table 3: criteria weight and rank by AHP methods.

Theme	Class/ Feature	Layers Weight	Rank
Geology	Aeolian Sand	0.40	2
	Alluvial fan sediment		4
	Alluvium		3
	Dibdibba Formation		5
	Sabkha deposits		1
	Upper Fars		2
Lineament density	Very High	0.20	5
	High		4
	Medium		3
	Low		2
	Very low		1
Slope degree	Very High	0.13	5
	High		4
	Medium		3
	Low		2
	Very low		1
Soil	Clay Soil	0.10	1
	Gypsum and Sand Soil		3
	Pebble Soil		4
	Pebble and Sand desert		5
	Salt Soil		1
	Sand Duns		2
Drainage density	High	0.08	4
	Medium		3
	Low		2
	Very high		5
	Very Low		1
Aspect	Very High	0.07	1
	High		2
	Medium		3
	Low		4
	Very low		5

$$GWPRI = \sum_{j=1}^{N}(Wj * Xj) \text{ .... } (1)$$

Where

GWPR: groundwater potential recharge index

Wj: is the normalized weight of the j theme

Xj: is the normalized weight of the j class of the theme

Table 4: Calculate consistence Matrix and WCS.

– Multiply each criteria value by its weight

Criteria	Geology	Soil	Lineaments	Slope	Drainage	Aspect	Criteria weight sum WCS
geology	0.41	0.41	0.39	0.4	0.4	0.36	2.35
soil	0.21	0.21	0.195	0.2	0.2	0.18	1.175
Lineaments	0.132	0.132	0.13	0.13	0.128	0.12	0.772
slope	0.1	0.1	0.0975	0.1	0.1	0.09	0.5875
drainage	0.08	0.08	0.078	0.08	0.08	0.072	0.47
Aspect	0.064	0.066	0.065	0.066	0.0568	0.06	0.3778

Table 5: Consistency Ratio and Consistency Index C.I.

Criteria	WCS	WC	Ratio WSC/WC	Λ max	C.I	Consistency ratio
geology	2.37	0.41	5.780488	6.158668	0.031	0.025
soil	1.27	0.21	6.047619			
lineaments	0.83	0.13	6.384615			
slope	0.64	0.1	6.4			
drainage	0.53	0.08	6.625			
Aspect	0.4	0.07	5.714286			

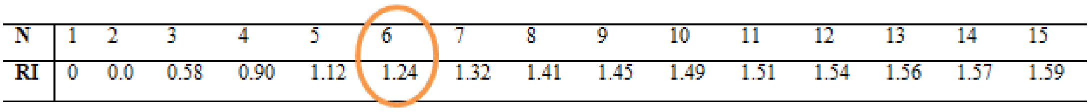
Λ max = (Sum of Ratio WSC/WC)/ number of thematic layers

Consistency index = (Λ max – n)/ (n-1) …………………. 2

Consistency ratio = consistency index (C.I)/ Random index ………………. 3

Random consistency index can be obtained using the standard values table (6)

Table 6: the average random consistency index (RI) for various types of N (mmm) Saaty (1980).



N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.59

N: criteria number
RI: random consistency index
Consistency ratio = 0.031 / 1.24 = 0.025

According to Saaty (1980) and Malczewski (1999) if the value of the consistency ratio is more than (0.1, standard consistency ratio) then a pairwise comparison has to be re-estimate, whereas if the value of the consistency ratio is less than (0.1) then the criteria weight are acceptable. The value of the consistency ratio is 0.025 less than the standard consistency ratio. Therefore, a pairwise comparison is possible.

RESULT AND DISCUSSION

▪ Generation thematic maps

– **Geology map:** One of the outstanding desert plateau alluvial fan patterns was the Al-Batin Alluvial Fan. Gravely sand, sandy gravel, and gypcrete is the main deposits of the layers, with silty and sandy clay layers and lenses serving as subordinate layers and lenses (Maala, 2009). The gravel size ranges from coarse gravel at the fan's apex in the Wadi Al-Batin channel to fine gravel. The maximum rank value was five for Dibdibba Formation (Figure 5a).

– **Lineament density map:** Faults, joints, folds, dikes, tectonic faults, and other linear or curved structures of the earth's surface are examples of lineaments. In hard rock terrains, lineaments are crucial for recharging subterranean groundwater, and groundwater potential remains high closer to lineaments (Dar *et al*., 2020). Simple and complicated linear elements of geological structures, such as faults and fractures are arranged in a straight or curving line, and discontinuities characterized as lineaments can be obtained via remote sensing (O'Leary *et al*., 1976). The lineaments map is generated from a shaded relief map of DEM (Figure 5f). The lineaments density map was classified into five classes (very high, high, medium, low, and very low). The northern part of the Wadi Al-Batin alluvial fan is characterized by the highest lineament density.

– **Slope gradient:** The slope gradient is one of the most important variables influencing groundwater and surface catchment features. Lower slope angles result in a lower hydraulic gradient, which improves infiltration and recharging (Ahmed and Al-Manmi, 2019). The slope gradient map of the present areas was created using DEM data. The slope's relationship with groundwater is proportionate to the slope's degree (Ribolzi *et al*., 2011). the slope gradient can be divided into four categories: flat with (2%), undulating with (2 – 8 %), rolling with (8 – 15 %), and hilly that (> 15%) (Figure 5b).

– **Soil map:** Soil is another major factor that influences the occurrence and distribution of groundwater and plays a significant role in water infiltration. that has an impact on groundwater recharge (Dar *et al*., 2020). Based on the work of (Buringh, 1957) and the Food and Agriculture Organization (FAO), six soil types are defined in the present region, which are clay soil, gypsum and sand soil, pebble soil, pebble and sand desert, salt soil, and sand dunes (Figure 5c).

– **Drainage density:** Drainage density is defined as the distance between stream channels divided by the length in square kilometers. Drainage density is inversely proportional to permeability (Bera and Ahmad, 2016). The kriging interpolation approach was utilized to conduct the line density with a spatial analysis tool, which was conducted using drainage lines, using ArcGIS 10.6 software. As a result, the drainage density index was determined using a mesh network in the Al-Batin area. The obtained values for each mesh were plotted at the grid's center, and the drainage density map was created using the coordinates of each mesh's center (Figure 5d). Drainage density is the result of interacting elements that influence surface runoff and has an impact on drainage basin sediment generation. The lower the drainage density, the more permeable the soil, the better the vegetation cover, and the lower the relief, while the higher the drainage density, the more permeable the soil, the better the vegetation cover, and the lower the relief (Dar *et al*., 2020). The drainage density map is classified into five classes (very high, high, medium, low, and very low).

– **Slope aspect:** It can be defined as the direction of change in each raster neighbor's value in the direction of the maximum rate of change. The sharpest slope's azimuth from the north is the direction of the compass (Huggett and Cheesman, 2002). The compass direction the surface faces at that point is specified by the aspect value. It is measured in degrees clockwise from 0 to 360 north, then straight north to complete the circle.

This variable has a direct impact on microclimates, which is particularly true in desert environments. On slopes of dry and semi-arid regions, flora patterns change depending on exposure to the sun. The northeast, southeast, and east sides of the slope will be warmer than the southeast, northwest, and flat basin parts of the region, which correspond to the rocky natures and primary faults of the fan (Singh *et al*., 2019) (Figure 5e).

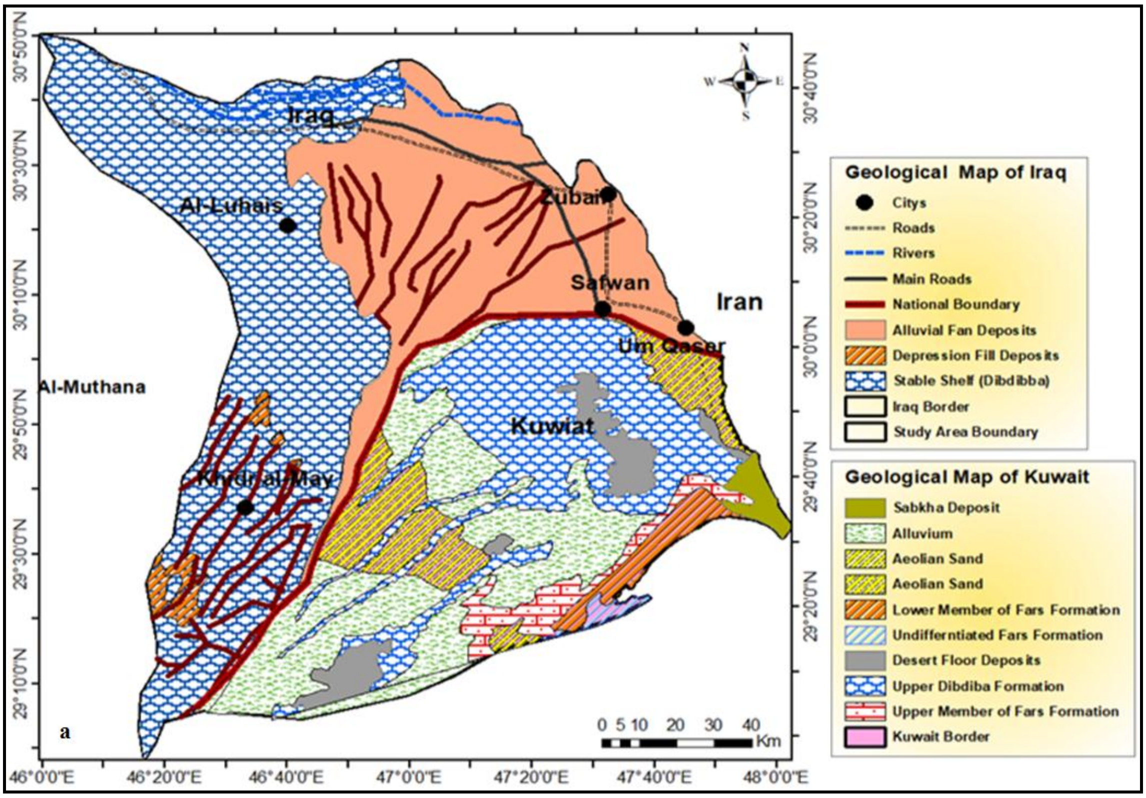


Figure 5a: Geological map.

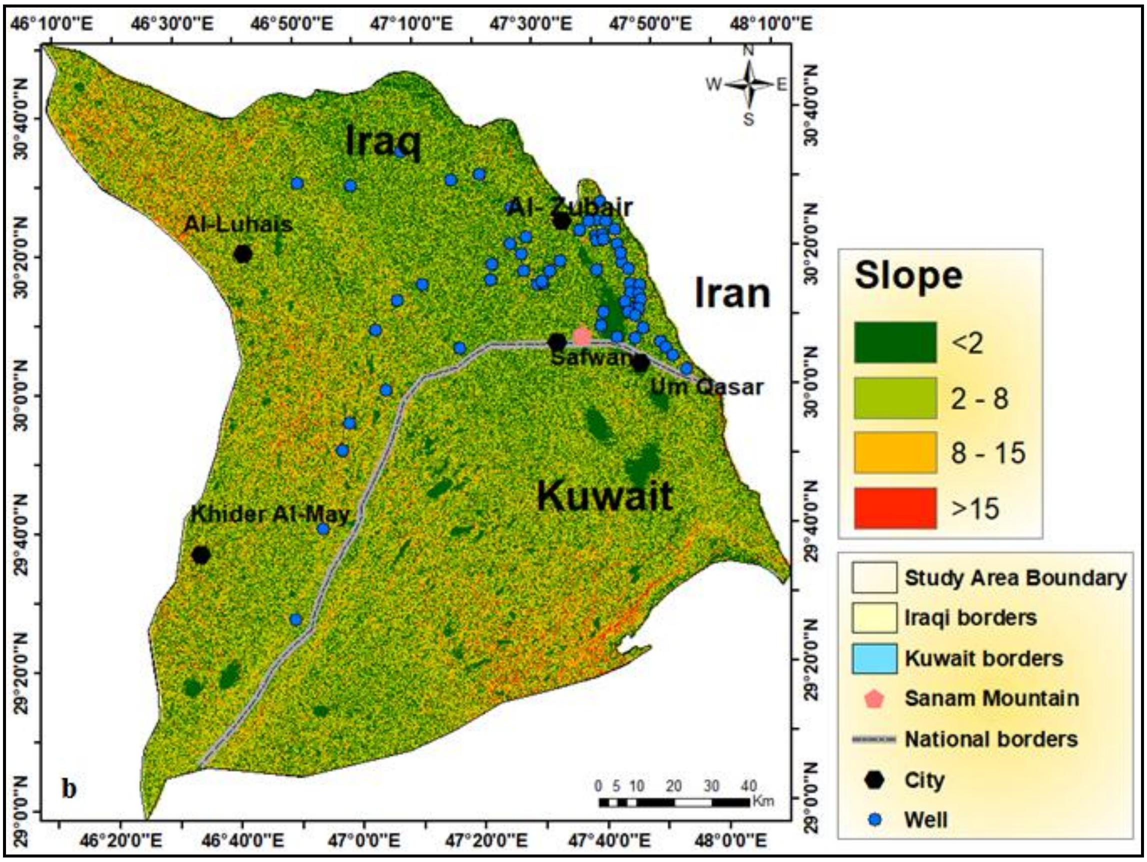


Figure 5b: Slope gradient map.

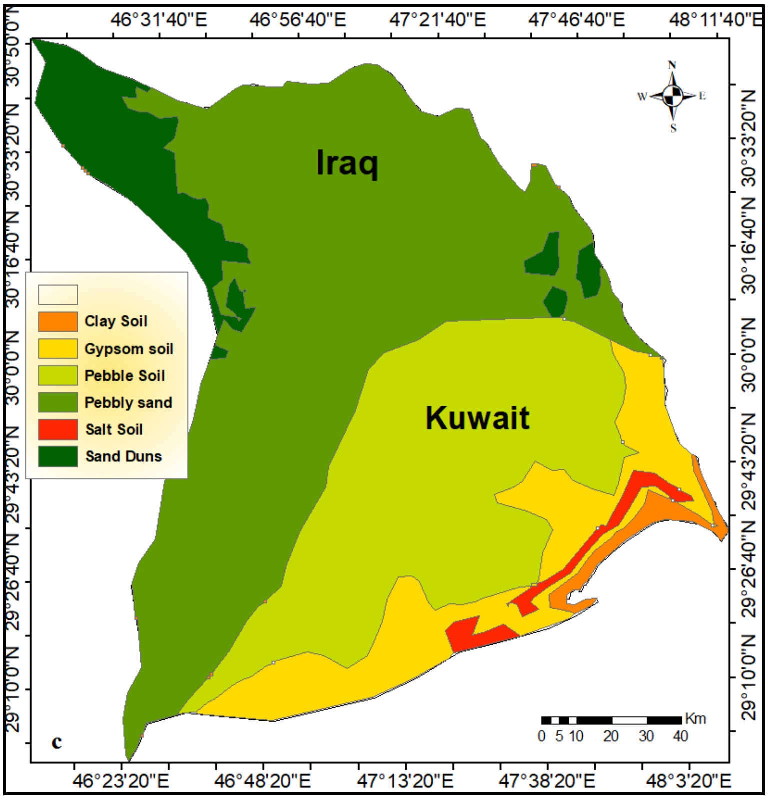


Figure 5c: Soil map.

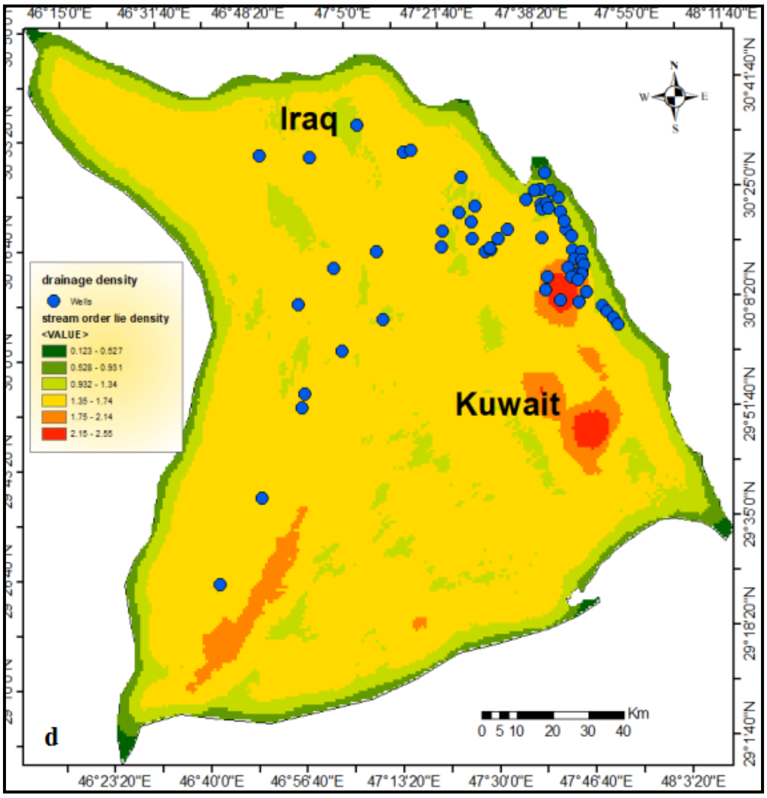


Figure 5d: Stream order map.

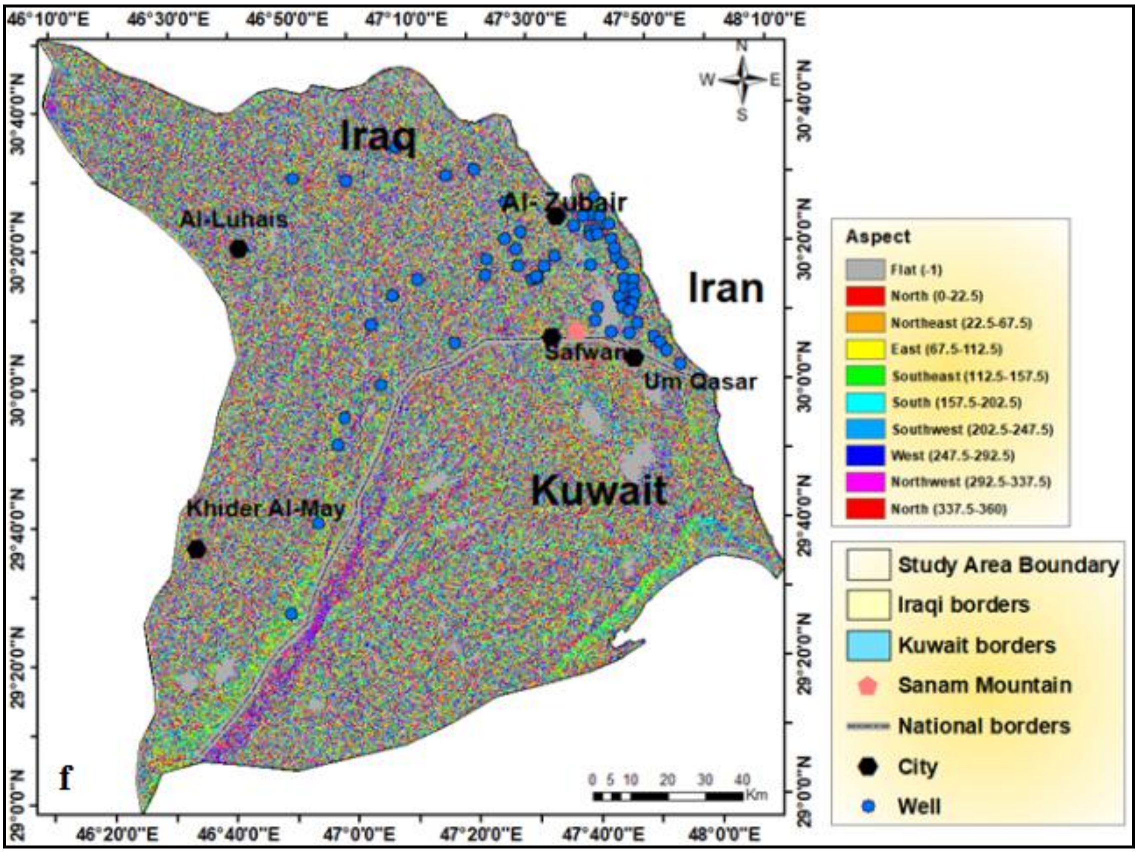


Figure 5e: Slope aspect map.

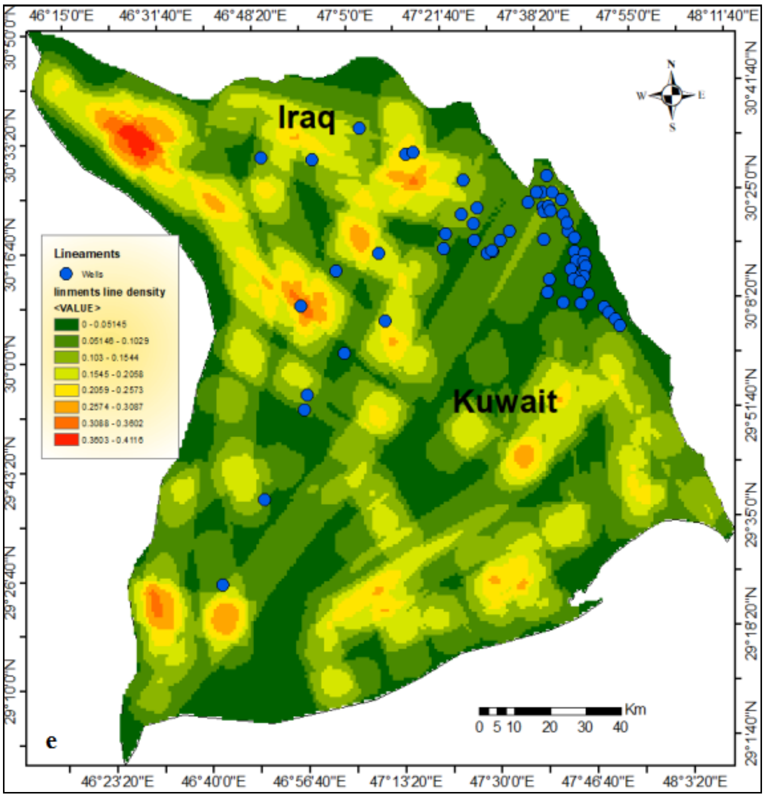


Figure 5f: Lineament density map.

DISCUSSION

AHP methods are used to delineate the GWPR map. Pairwise comparison was estimated for all six thematic layers (Geology, lineaments density, slope gradient, drainage density, soil, and slope aspect), Based on the weights obtained for the selected maps, a reclassification map of them was created (Figure 6a, b, c, d, e, and f). The weights of this map were given according to their relative importance of them (Table 1). After the weights of thematic layers, the data sets were combined in GIS using equation (1). The final groundwater potential recharge map is in Figure (7).

Based on the research area's characteristics. The groundwater potential zones and scores were examined using a variety of metrics. The AHP technique divides the entire into three zones based on GWPR values: High, moderate, and Low. We can observe from the final GWPR map that the east and northeast parts of the alluvial fan have more groundwater recharge potential due to increased infiltration rates because of the gravely and sandy soils besides the agricultural land use of the present areas. However, the other section of the fan, which ranged from high, low to moderate, required artificial replenishment. The high potential zone covers most of the Wadi Al-Batin alluvial fan ~70% of the total area where it extends with the Euphrates fault to the Jal Al-Zor in Kuwait, Moderate potential zone is found in the west and the middle part from the fan-covered 25% of the total area, Low potential zone is found in some area in the west and southwest parts of the fan covered ~5% (Table 7).

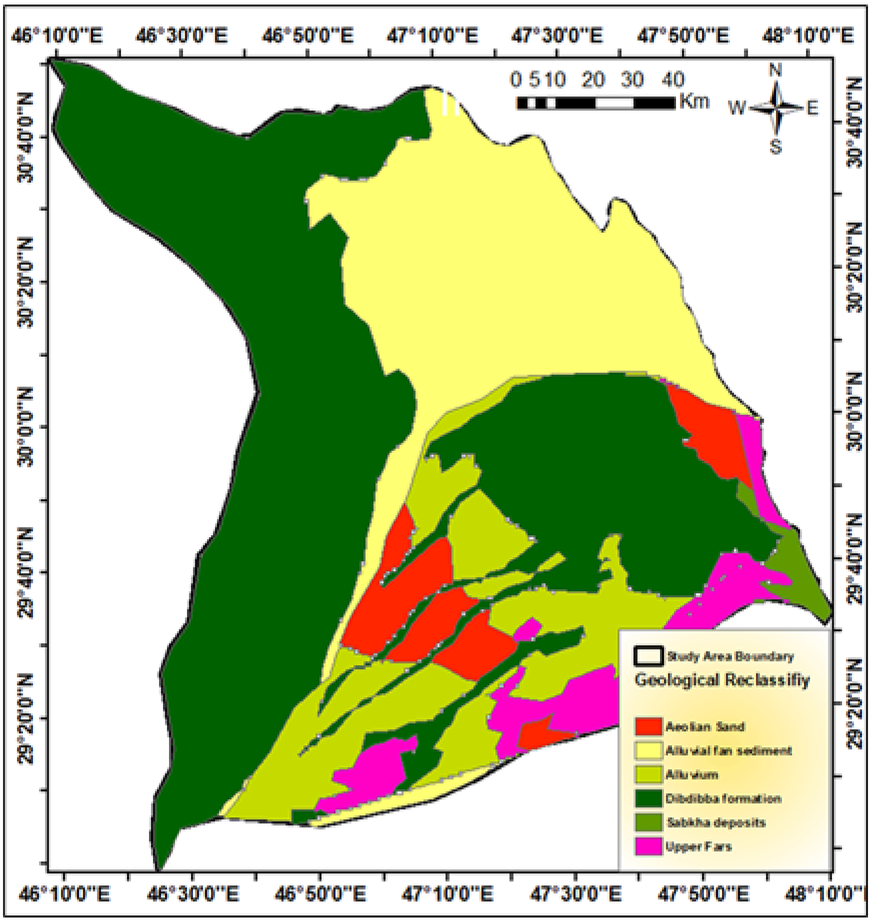


Figure 6a: Reclassify of the geological map.

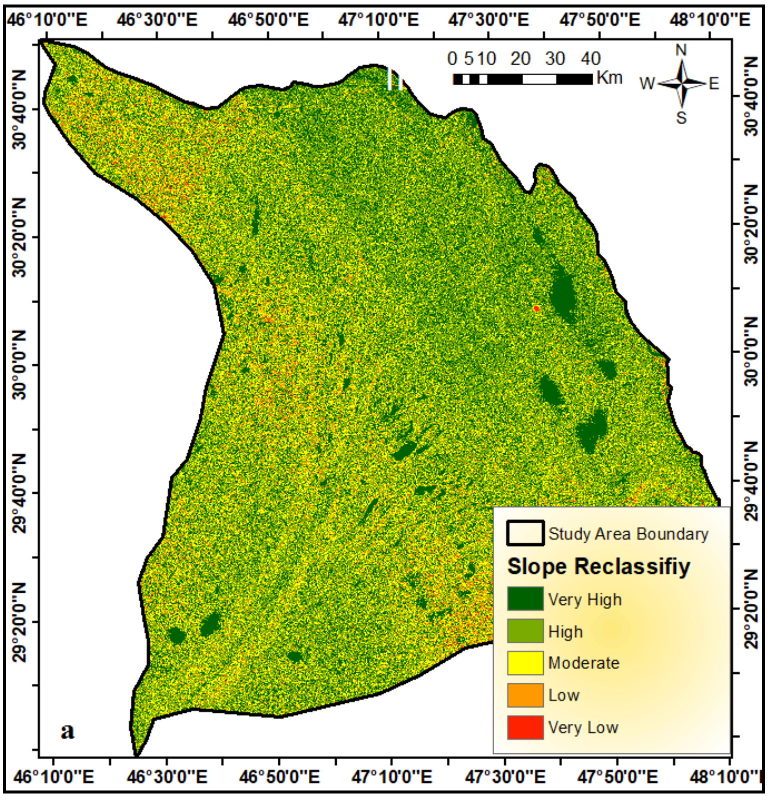


Figure 6b: Reclassified slope greident map.

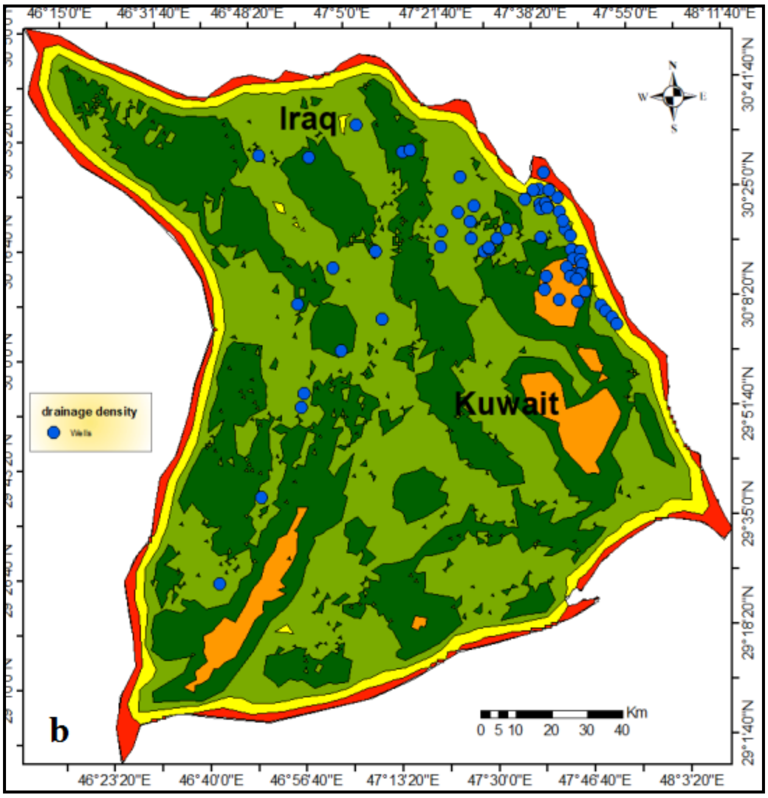


Figure 6c: Drainage density map.

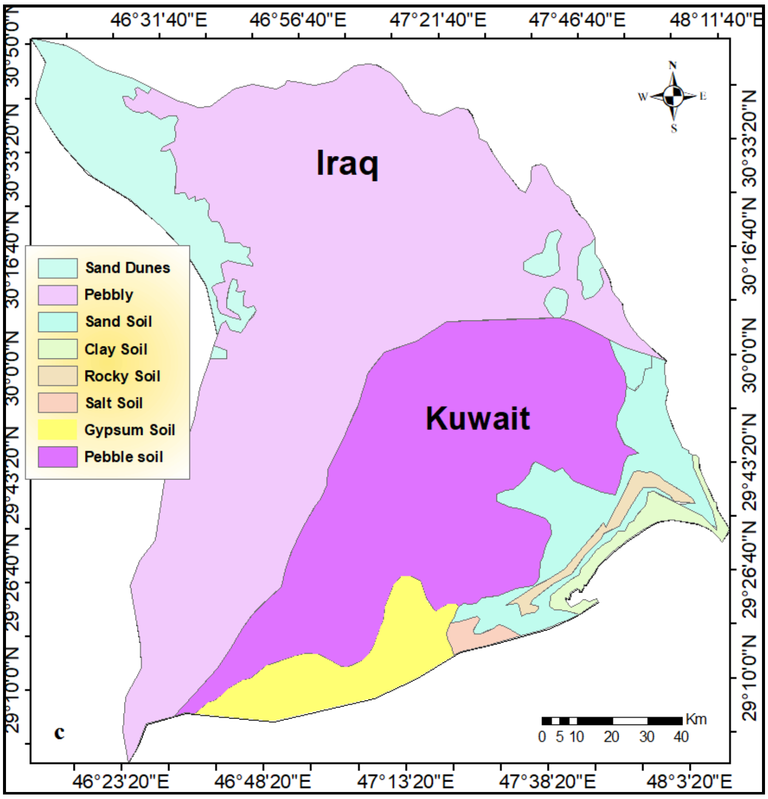


Figure 6d: Reclassified soil map.

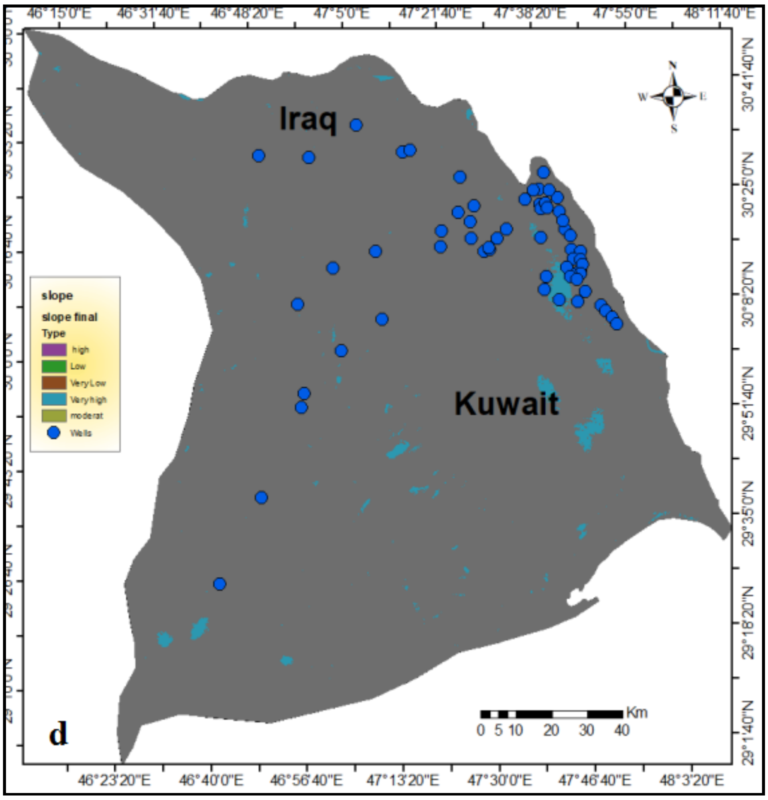


Figure 6e: Reclassified slope aspect map.

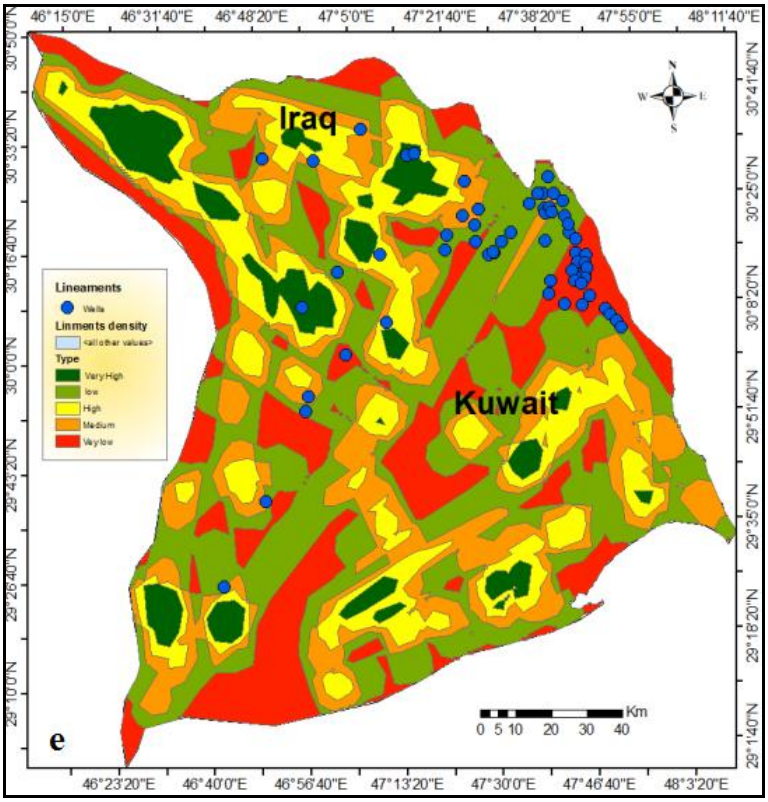


Figure 6f: Reclassified lineaments map.

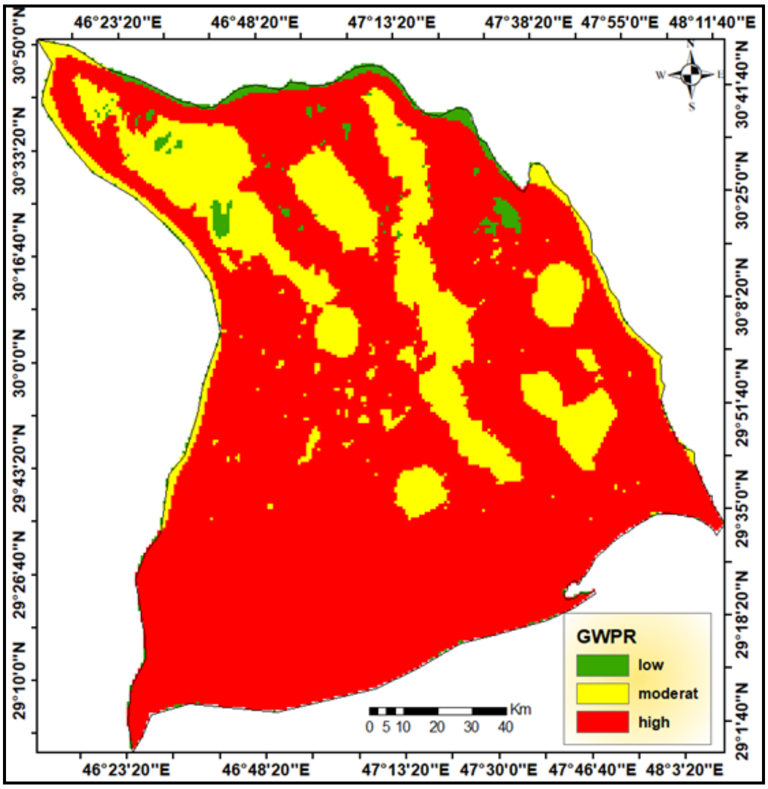


Figure 7: Groundwater potential recharge zone map.

Table 7: groundwater potential recharge area.

GWPR	Area (%)
High	70%
Moderate	25%
Low	5%

CONCLUSION

- Tectonically, Wadi Al-Batin alluvial fan is located within the Mesopotamian zone, the main Faults that affect the present study area are The Takhadid Al-Qurna Fault, Al-Batin Fault, and Euphrates-Abu Jir Fault.
- Hydrologically, the main aquifer of Al-Batin was Dibdibba regional aquifer in Kuwait, which stretches through Saudi Arabia. As sharing countries to the regional aquifer, Kuwait, Saudi Arabia, and Iraq depend on groundwater from the Dibdibba aquifer.
- The AHP method was used to delineate the groundwater potential recharge zone by using GIS and data from DEM and satellite images.
- Six thematic maps were used to design the GWPR map (geology, lineaments density, slope gradient, drainage density, soil, and slope aspect), and the weight of each thematic map was estimated by the AHP method.
- Geology and soil maps were reclassified into six classes, while, lineament density, slope gradient, and slope aspect were reclassified into five classes.
- Finally, groundwater potential recharge map results show that the high potential zone is found in the east and northeast for Wadi Al-Batin alluvial fan, the moderate potential zone is found in the west and SW, and the low potential zone is found in the east and southeast of the Wadi Al-Batin alluvial fan.

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