A GIS-Based Multicriteria Decision for Groundwater Potential Zone in the West Desert of Iraq

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Abstract. In arid and semi-arid parts worldwide, the investigation of the groundwater potential recharging zone is a main target to recompense the massive shortage in rainfall and surface water supplies. Recently, the combination of Remote Sensing (RS) and Geographical Information System (GIS) techniques became possible to overcome the water scarcity and supply all the water requirements for the population, agricultural and commercial purposes in the western Iraqi desert. Various thematic layers such as geology, slope, soil infiltration, land use and land cover, rainfall, drainage density, and lineament density were derived from RS data like Landsat 8 satellite images and the SRTM Digital Elevation Model (DEM) and published Iraqi geological maps. The thematic map of the parameters was generated and transferred into the raster form by employing the raster conversion tool in ArcGIS 10.8 software, and each layer was subjected to different assigned weights through adopting Analytical Hierarchical Process (AHP). The prospective map of the groundwater recharging zone in the study region is categorized into five regions. The output map shows that 3.21% of the area locates in the perfect potentiality zone, followed by 10.75% in the good potentiality zone, 38.6% moderate potential zone, 42.9% in the poor groundwater zone, whereas only 4.44% of the study area falls under the very high prospective zone. To attain the sustainable management of the groundwater in the Iraqi western desert, this study provides a primary methodology and significant database for the local management of water resources by adopting the groundwater perspective map.

Keywords: Analytic Hierarchy Process (AHP), GIS, RS, Groundwater potential zone, Iraqi western desert.

1. Introduction
Groundwater represents a unique valuable water resource and the sustainable management of this resource is depending on the available quantity and quality. Arid and semi-arid regions (that constitutes 35 % of the earth's land) are already facing water scarcity problems due to many reasons like climate change, population expansion, and the growing water demand for urban development and agricultural activities [1]. About 30% of the freshwater around the globe is latent and confined as groundwater, whereas but 0.3 % in form of lakes, rivers, marshes, and reservoirs [2]. The optimum utilization of groundwater resources is very necessary especially when the available quantities of the surface water are insufficient to provide all water requirements for drinking, irrigation, rural and urban expansion, further for developing industrial activities [3]. During the few recent decades, computer technology has been widely applied in hydrological studies. The techniques of Remote Sensing (RS) and Geographic Information System (GIS) has been intensively employed in the exploration, projection, and management of groundwater resources.
Remote sensing (RS) technology allows the exploration of the earth's surface with a large scale, therefore, it is mostly concerned with identifying groundwater potential zones [4,6]. The delineation of groundwater prospective zones is fundamental for sustainable utilization of groundwater and further development for irrigation systems [2]. Kaliraj et al. [7] proved in their study that modern geospatial techniques such as RS and GIS can be used to delineate the potential recharging zones of the groundwater with desirable results. The occurrence and distribution of the groundwater depend on the climatic and regional conditions, surface and sub-surface features like underlying rock fractures, and land cover type, and the hydrological characteristics of the region [8,10]. Many researchers such as [6,11,13] have recently used RS and GIS approaches for the exploration of suitable artificial recharging zones of groundwater. Applying the Geospatial techniques like RS and GIS requires preparing various thematic maps for surface and subsurface layers of the earth and then integrating these layers by giving each layer a weightage value base on its influence on the existence and occurrence of groundwater [14]. Most of the published studies identified the resultant map of the groundwater potential zones as very good, good, moderate, poor, and very poor zones. Analytical Hierarchal Process (AHP) method evolved by Saaty, 1980, indicates analyzing multi datasets in form of a pair-wise matrix, computing the geometric mean, and normalizing the assigned weights for each parameter [15,17]. This study aims to demarcate and identify the prospective recharging zones of groundwater in the AL-Mohammedi basin by using RS, GIS, and AHP techniques.

2. Study area
Al-Mohammedi valley basin locates within the administrative boundaries of Heet district in the west desert of Iraq. The study region constitutes about (2303.12 Km²) and lies between 33° 0′ 0″ N - 33° 45′ 0″ N and 42° 0′ 0″ E – 43° 0′ 0″ E (see Figure 1) with elevation ranges between 54 m to 364 m. The area is almost portrayed by limestone, sandstone, and claystone terrains with arid climatic conditions that receive less than 200 mm per year of rainfall. The present study area is covered with three soil types are silty loam, sandy loam, and clay loam [18]. The major economic activity in the region is agriculture that is irrigated depending on the surface subsurface water resources [19]. Hence, the inclusive management of the water resources a fundamental concern in the Al-Mohammedi valley basin.

![Figure 1. Location map of the study area.](image-url)
3. The influence criteria

3.1 Geology

Geologic formation constitutes a governing factor in containing, movement, and occurrence of groundwater. The geologic map of the study region has been derived from the geologic sheet of Iraq by the Iraqi geological survey establishment. The geologic map shows that AL-Mohammedi valley is underlain by four geologic formations, as shown in Figure 2a: Nfayil, Zahra, Euphrates, and Injana. The first geologic formation is Nfayil, the largest geologic formation with an average area (934.27) km$^2$ that constitutes (40.56 %) out of the whole study. This formation comprises two parts. The lower part contains green marl and fossiliferous limestone, while the upper parts include reddish-brown claystone, sandstone, and salt stone with a thin layer of limestone [20]. Zahra formations cover (674.83) km$^2$ about (29.30%) of the total area of Al-Mohammedi valley Figure 3a. The lithological composition of this formation is limestone, sand, and sandy marls [21]. Euphrates’ formation extends along the right bank of the Euphrates River and comprises about (588.46) km$^2$ that constitutes (25.55%) of that total study area. The structure of this formation is fossiliferous, chalky dolomitic, and limestone [22]. The fourth formation is Injana that covers (105.60) km$^2$ which forms (4.58%) of the total study area.

Figure 2. (a) Geology, (b) slope, (c) soils texture, (d) soils infiltration, (e) drainage density, (f) lineament density, (g) land use and land cover, and (h) rainfall maps of the study area.
Injana formation consists of alternated depressions of sandstone, siltstone, and claystone with a thin layer of gypsum horizons and limestone in the lower part [20]. Al-Jiburi and Al-Basrawi [23] classified in their study the Euphrates and Injana formations from within the highest water-bearing formations beneath the west desert of Iraq. In contrast, others considered a yielded aquifer due to the structural properties or their location above the regional groundwater level.

3.2 Slope
The factor of slope gradient has an influence relation in the estimation of percolated amounts of rainfall. Depending on the Digital Elevation Model (DEM) data, the slope map for the study region shown in Figure 2b was extracted using the slope function in ArcGIS 10.8 software and presented in degrees. Slopes with steeper declinations produce less recharge due to the rapid flow of runoff, which will reduce the infiltrated rates into the saturated zone [8], [24]. The slope map was regrouped into five classes in this research, and each class was weighted based on slope distribution aspects. Slopes with (0-1°) refer to a plane area and a perfect recharging parameter. Ranges (1-2°) are good for recharging, whereas larger slope gradients (more than 10°) are very poor for recharging groundwater zone due to the rapid runoff and lower infiltration rates.

3.3 Soil infiltration
Infiltration is the soil property that allows water to percolate from the surface to the sub-surface layers of the ground. It is a measure of how depth that water can percolate vertically through a specific period. The infiltration amounts to the aquifer systems from the surface water are variably controlled by the soil characteristics such as soil texture, soil type and porosity from hand, and rainfall intensity, slope, and
vegetation cover from another hand [25]. The structure of the soil is the main parameter that influences the infiltration rates of surface water, and it varies spatially based on grain size as illustrated in Table 1. Soils with grained structures like coarse sand have less and slower rates of infiltrated water than fine-grained soils. The soil texture map for the study region is prepared from the Food and Agricultural Organization (FAO) with a scale of 1: 5 000 000. The map consists of many polygons. Each one includes different types and characteristics of soils. The soil map, Figure 2c, shows that three types of soil texture are common in the region: 93.01% of the study area with silty loam, 3.95% with sandy clay loam, and 3.04% with sandy clay loam. From soil type map, Figure 2c, and Table 1, the soil infiltration map for the study area (see Figure 2d).

![Soil Texture Map](image)

Table 1. Soil infiltration rates for different textures of soils [8]

| No. | Soil texture          | Infiltration rate (mm/hr.) |
|-----|-----------------------|----------------------------|
| 1   | Gravelly loamy sand   | 30                         |
| 2   | Sandy loam            | 20-30                      |
| 3   | Loamy sand            | 15-20                      |
| 4   | Sandy clay loam       | 10-15                      |
| 5   | Silty clay loam       | 7.5-10                     |
| 6   | Clay loam             | 5-10                       |
| 7   | Clay                  | 1-5                        |

Figure 3. Percentages (%) of the area that covers the characteristic of (a) geology, (b) soil texture, (c) LULC in the study region.
3.4 Drainage density
Drainage systems have a governing role in identifying the recharging volume of surface water into groundwater. Drainage density reflects the total length of the stream features per unit area, and it increases by the increasing distance between reaches [26]. The drainage systems for an area can be identified by the type and texture of the geologic formation, absorbing capacity of soil for rainfall, slope, and vegetation type [27]. In the Al-Mohammadi basin, the drainage density map was generated from the (DEM) data (30m resolution). After that, we used ArcGIS10.8 to extract the network drainage from the flow accumulation tool and finally the drainage density map obtained by applying the line density tool to the drainage network map. The drainage density map of Al-Mohammadi basin (see Figure 2e) varies from 0 to 4.52 km/km2. The higher density of the streams concentrates in the middle parts of the basin while the western and southern parts have a lower drainage density. The feature of drainage density is considered a reversal function of the permeability as the higher density of the streams increases the surface runoff and therefore the infiltration rates will be reduced hence; regions with a high density of drainage are considered not appropriate for the development of groundwater [28].

3.5 Lineament density
Lineaments are linear features that describe the surface topography and underlying structural phenomena like faults and rock fractures. The presence of lineament features almost refers to a permeable zone hence, high lineament regions are considered a significant index for the high prospective groundwater zone [29]. The lineament density map for the Al-Mohammadi basin (see Figure 2f) is obtained from Landsat 8 image data and mapped by using ArcGIS 10.8 software through line density tool based on the following formula:

\[
LD = \sum_{n=0}^{n} \frac{L_i \text{km}}{A \text{km}^2} = \text{km}^{-1}
\]

The lineament density values range from 0 to 1.2 km/km² and the intensive sectors are prevalent along with central parts of the basin while other parts (north and south) indicate less dense lineaments. Two main trends of fault system N-S, E-W are prevalent in the study area, and each system consists of two perpendicular or nearly perpendicular trends [30].

3.6 Rainfall
Rainfall is the main hydrological factor that directly influences the recharging groundwater aquifers and the fluctuation of the groundwater table. Generally, the west desert of Iraq is categorized as an arid area due to the lack of precipitation amounts (less than 200 mm per year) with discontinuous intervals. The rainfall distribution map of the Al-Mohammadi basin, Figure 2f, is mapped based on the published annual precipitation data for AL-Ramadi, Heet, and Haditha stations [31]. The annual amounts of rainfall in the study site are between 104.57 mm and 108.63 mm situated along the western bank of the river, whereas it reduces toward the east and southern parts of the basin. More than 48% of the study area annually receives between (100.98 and 104.57) mm, while the other parts receive a little higher amount. There is a reverse correlation between rainfall intensity and infiltration. High rainfall intensity leads to little infiltration rates and more amounts of surface runoff [8,32].

3.7 Land use and landcover
Land use and land cover map were extracted from remote sensing data using Landsat 8 images at 30 m resolution, which was downloaded from the United States Geological Survey (USGS) website. The supervised image classification tool in ArcGIS was used to identify the land cover units for the study area. Five main classes (see Figure 2g) were categorized from the study region cover are barren lands, croplands, shrublands, herbaceous vegetation, and built-up lands. The areal extent for the land use classes is shown in Figure 3c. The land cover units directly influence groundwater recharging whereas increase or decrease the percolated amounts of the surface water into underground layers [33], [34]. Vast areas of the study region (about 94%) are covered with barren lands due to the lack of rainfall amount in the region. Barren lands are considered unsuitable for groundwater recharging in contrast with
herbaceous vegetation, which is considered a perfect indicator for groundwater development [27]. Croplands cover a small percentage of the study region about (2.34 %), and this cover is considered very important in identifying groundwater potential zone because it reduces runoff and increases infiltrated rates of surface water used to irrigate the crops [35].

![Flowchart for the process of detecting groundwater potential zones.](image)

**Figure 4.** Flowchart for the process of detecting groundwater potential zones.

4. Materials and methods
The present study is based on the conjunction of Remote sensing (RS) and Geographic Information System (GIS) techniques to demarcate the prospective map of the groundwater zones. Seven influence parameters such as geology, slope, soil infiltration, lineament density, drainage density, land use and land cover, and rainfall were considered. Multi-Criteria Decision Making (MCDM) and Analytical Hierarchal Process (AHP) approach were utilized to calculate and normalize the required weights for all the thematic layers. The geological formations map of the study site was derived from the geological map of the Iraqi western desert obtained from the Iraqi Geological Survey establishment [20]. Slope, drainage density, and lineament density maps are generated from the Digital Elevation Model (DEM) with a spatial resolution (30×30 m) were acquired from United States Geological Survey (USGS) ([https://www.earthexplorer.usgs.gov](https://www.earthexplorer.usgs.gov)). The land use and land cover map were generated from Landsat 8 satellite image (May 2020) at 30 m resolution from the USGS website, and by using the supervised image classification tool in ArcGIS 10.8. The map of soil infiltration was acquired from the Food and Agricultural Organisation (FAO) soil map of the world at a scale of 1:5 million.
All the thematic layers that used in this study were transformed into the raster format by using the raster conversion tool in ArcGIS 10.8 and then reclassified according to the assigned weights.

Table 2. Assigned weights and ranks for the seven thematic layers.

| Parameter          | Feature class          | Scale Value | Normalized weights (%) |
|--------------------|------------------------|-------------|------------------------|
| Land use and Landcover | Croplands             | 5           | 14                     |
|                    | Herbaceous land        | 4           |                        |
|                    | shrub lands            | 3           |                        |
|                    | Barren lands           | 2           |                        |
|                    | Built-up               | 1           |                        |
| Slope (in degree)  | 0-1                    | 5           | 10                     |
|                    | 1-3                    | 4           |                        |
|                    | 3-5                    | 3           |                        |
|                    | 5-10                   | 2           |                        |
|                    | 10-18.93               | 1           |                        |
| Geology            | Euphrates              | 5           | 6                      |
|                    | Injana                 | 4           |                        |
|                    | Nfayil                 | 3           |                        |
|                    | Zahra                  | 2           |                        |
| Lineament density  | 0-0.22                 | 1           | 20                     |
| (km/km²)           | 0.23-0.44              | 2           |                        |
|                    | 0.45-0.66              | 3           |                        |
|                    | 0.67-0.88              | 4           |                        |
|                    | 0.89-1.2               | 5           |                        |
| Drainage density   | 0-0.439                | 5           | 4                      |
| (km/km²)           | 0.44-1.01              | 4           |                        |
|                    | 1.02-1.62              | 3           |                        |
|                    | 1.63-2.33              | 2           |                        |
|                    | 2.34-4.52              | 1           |                        |
| Rainfall (in mm)   | 107-108                | 5           | 28                     |
|                    | 105-106                | 4           |                        |
|                    | 103-1104               | 3           |                        |
|                    | 100-102                | 2           |                        |
| Soil infiltration  | 10-15                  | 5           | 18                     |
| (in mm)            | 7.5-5                  | 4           |                        |
|                    | 5-10                   | 3           |                        |

5. Assignment and normalization of weights
Depending on the AHP approach, the pairwise comparison matrix (see Table 3) of the thematic layers has been derived, while the calculation of the eigenvector method determined the weighted normalized matrix. Table 3 illustrates that the rainfall parameter is the most important one, which weighted with 28% of the total weighted values, followed by 20% for the land use and land cover, 18% for the soil
infiltration, 14% for the slope, 10% for the geology, and 6% for the drainage density. The consistency ratio has been calculated and found 7.5% that should be less than 0.1 to make sure that all the specified weights are consistent [36].

### Table 3. The pairwise comparison matrix.

| Parameter        | LULC | Slope | Geology | Lineament density | Drainage density | Rainfall | Soil infiltration |
|------------------|------|-------|---------|-------------------|------------------|----------|------------------|
| LULC             | 1    | 3     | 3       | 1                 | 5                | 1/3      | 1/3              |
| Slope            | 1/3  | 1     | 3       | 1                 | 1/5              | 3        | 1/3              |
| Geology          | 1/3  | 1/3   | 1       | 1/5               | 3                | 1/3      | 1/3              |
| Lineament density| 1    | 3     | 5       | 1                 | 5                | 1        | 1               |
| Drainage density | 1/5  | 1/3   | 1/3     | 1/5               | 1                | 1/5      | 1/3              |
| Rainfall         | 3    | 5     | 3       | 1                 | 5                | 1        | 3               |
| Soil infiltration| 3    | 3     | 3       | 1                 | 3                | 1/3      | 1               |

6. **Delineation of the groundwater prospective zones**

Groundwater prospective zones are nondimensional quantities that help in the process of groundwater prospective map declination [37], [38]. The weighted overlaying tool in the ArcGIS 10.8 tool is utilized to demarcate the prospective map of groundwater zones by employing the following formula [3,16,39]:

\[
GWPZ = Rf_w Rf + LULC_w LULC + Ge_w Ge + S_w S + Si_w Si + Ld_w Ld + Dd_w Dd
\]  

(2)

Where \( w \) = the assigned weight for each parameter; \( wi \) = assigned rank for each featureless; \( Rf \) = rainfall; \( LULC \) = land use and land cover; \( Ge \) = geology; \( S \) = slope; \( Si \) = soil infiltration; \( Ld \) = lineament density; \( Dd \) = drainage density. Based on the related previous studies, suitable weights and ranks were given for each influence parameter and their sub-classes based on their effect on groundwater storage, occurrence, and movement. The highest weights and ranks refer to the high potentiality of groundwater, whereas the lowest weights and ranks reveal the lowest groundwater potentiality [40]. The final output map of the groundwater prospective zone as shown in Figure 5 has been reclassified into five categories e.g., very poor, poor, moderate, good, and very good zones. Figure 6 shows the five classes and their areal percentages of the study area.

![Figure 5. The groundwater potential map for the study site.](image)
7. Conclusion
The present study is concerned with detecting the groundwater potential recharge zones (GWPZs) by using RS, GIS, and AHP techniques for the AL-Mohammedi valley in the western Iraqi desert. Different thematic maps of geology, lineament density, land use and land cover, rainfall, and slope maps were prepared from Satellite images, topographic maps, and conventional data. Various weightage values with corresponding classes were given for individual themes by applying the AHP technique. The groundwater prospective map in the study region was produced integrating all the thematic layers in the GIS environment. The results show that the study area was categorized into five prospective zones of groundwater which are very poor (4.44%), poor (42.98%), moderate (38.6%), good (10.7%), and very good zones (3.21%). The very good prospective zones are generally locating in the middle and western parts of the study area, whereas the very poor potential zones are locating in the south and eastern parts of the region. It is very necessary to construct a structure for the artificial recharge on the mainstream patterns, overall management, and promoting sustainability of the groundwater resource in the future.

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