Research Article

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The main impacts of a managed aquifer recharge using AHP-weighted overlay analysis based on GIS in the eastern Wasit province, Iraq

https://doi.org/10.1515/eng-2022-0484
received May 31, 2023; accepted July 02, 2023

Abstract: The management of groundwater recharge success and sustainability depends on many site characteristics. It is essential to integrate the maps of site's suitability and characteristics to identify suitable areas. The purpose of this study is to use a geographic information system (GIS) to find potential places for a project using managed aquifer recharge (MAR) in the eastern Wasit province, Iraq. Data for four effective criteria, terrain slope, Soil type/texture, drainage density, and hydrogeological efficiency, were collected, and a categorization map for each GIS criterion was subsequently created. The four steps are performed to identify this site: defining the problem, screening for the suitable areas, after the suitability map, and after the screening; the suitability mapping is divided into two zones: suitable zone and unsuitable zone. The results indicate that the site suitability for conducting aquifer recharge was classified into five categories, i.e., very high, high, moderate, low, and very low potentiality. These areas cover 26.83, 34.71, 24.98, 11.56, and 1.79%, respectively. GIS is widely acknowledged as an efficient approach for choosing MAR sites. This approach gives a better reference for analyzing suitable sites and the potential implications of applying MAR in an aquifer in similar water-stressed areas.

Keywords: GIS, MAR, groundwater recharge

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1 Introduction

Surface and groundwater play critical roles in the water supply system. Climate change, economic expansion, urbanization, and population increase have produced water scarcity and limited economic progress in many nations in recent decades. Groundwater is used as an alternate water supply when surface water is lacking. It is a key irrigation water supply, particularly in drought-prone deserts or semi-arid regions [1,2]. Efficient groundwater recharge management is necessary to meet the growing water demand [3]. The managed aquifer recharge (MAR) is a practical solution to the drought issue because of the amount of water during the rainy season and the drop in surface water that occurs during the dry season [4]. The approaches of MAR are categorized into five basic categories, which are further separated into several MAR types: (a) spreading methods; (b) shaft, well, and borehole recharge; (c) induced bank infiltration; (d) in-the-channel alterations; and (e) the rainwater and runoff vesting [5,6].

The research and monitoring of the Earth's resources have evolved since the first flight of the Earth Resources Technology Satellite (Landsat-1) in July 1972. Data from optical and microwave satellite remote sensing (SRS) provided useful information for identifying and predicting potential water resource locations in a variety of climatic conditions throughout the world [7–9]. The advancement of SRS enabled the investigation of various aspects of hydrological factors [10] and promising water resource regions to be forecast using multi-criteria [11]. Data from synthetic aperture radar (SAR) microwave remote sensing are critical for exposing concealed geologic characteristics [12]. Several studies have effectively used radar data, such as Radarsat-1, ALOS/PALSAR, and SRTM, to locate water supplies [13]. The knowledge-driven Analytical Hierarchy Process (AHP) method [14] and, in the present research, geographic information system (GIS)-based and weighted overlay techniques (AHP) are used to create a suitable site map for applying the MAR. A solution to the complicated choice analysis based on hierarchical ordering criteria has been found by using this multi-criteria decision-making approach extensively in various prediction studies [15,16].

Iraq is now suffering from a water crisis as a result of water imports from neighboring nations that are considered as a source of water supplies. Based on the ground's spectral reflection, MAR may be used to learn about a variety of ground phenomena, including soil, slope, and geomorphology [17,18]. One of the most important is the research on water and the possibility of its occurrence, especially given the availability of space and field data [19]. Remote sensing and GIS are important for managing and developing water resources [20]. The recent water crisis in Iraq has stimulated the performance of applied research for places that retain groundwater; therefore, developing groundwater potential zone maps based on GIS and remote sensing has become highly significant. Water resource protection is critical in Iraq. Thus, the government began monitoring groundwater for effective management. An essential instrument for managing water resources is hydrogeological mapping [17]. The main objective of this work is to use a GIS tool and the AHP methodology analysis to find possible places for the use of MAR in the eastern Wasit region of Iraq. The study findings may be utilized to gain insight and understanding of the AHP analysis methodologies used to discover the best places for MAR applications in urban areas.

2 Study area

The study area is situated in Iraq's Wasit Province's eastern region, which covers about 4409.94 km^2 and is located nearly 964 m above sea level; boundaries extend from longitudinal (45°30′–46°20′ east) and latitude (32°40′–33°30′ north). The general slope of the land is from the eastern boundary and from the northeast to the southwest toward the center. This study's geographic location is depicted in Figure 1.

Parallel to borders separating Iraq and Iran are observed are followed by low places and valleys to collect water from highland areas and mountain heights. This variation in height was reflected in the effective flow of rain and torrential waters toward the low areas, and thus, they are suitable places for operations of groundwater recharge. The study area's vegetation is mostly created during the winter and spring seasons, which are the times of rain; in the summer, the weather is hot and dry, without vegetation, as there is no surface water. The only available groundwater that can be used and harness the wealth of this region.

3 Materials and methods

The application of GIS integration The AHP of the scientists was utilized to develop a map displaying the study region's ideal locations for MAR application. The data for this investigation were acquired from a variety of sources (Table 1). Utilizing data gathered from various sources in a raster format using GIS and remote sensing techniques, four parameters – the slope, soil, drainage density, and Topographic wetness index (TWI) of the research area – were determined.

The study area's digital elevation model (DEM) map is a raster depiction of a continuous surface where each cell represents a particular location's elevation. Using the slope and curvature tools in the ArcGIS Spatial Analyst Tools, the slope map was built straight from the DEM map. The flow direction map (the way the stream runs in each cell) was then obtained from the filled DEM map in order to create a sinkless/depressionless DEM. The flow accumulation raster map was then produced using the flow direction map. The ArcGIS Spatial Analyst tools, which featured Hydrology capabilities like Fill, the Flow Direction, and the Flow Accumulation, were used to fill the DEM map, determine flow direction, and compute flow accumulation. The drainage density map was produced from the flow accumulation map using the ArcGIS environment's Raster Calculator tool, and the drainage network map was produced using the Line Density tool in the Spatial Analyst Tools of ArcGIS. Using equation (equation (1)) [21], the drainage density (km/km^2) was calculated:

$$\text{Drainage density} = (\Sigma \text{Hi} \times \text{Li})/A, \tag{1}$$

where Hi is the width of the stream. Li signifies the entire length of all stream drainage in kilometers, and A denotes the size of the study area in km^2.

The TWI map of the research area was created in the ArcGIS environment using Spatial Analyst Tools' Raster Calculator and an equation (equation (2)) [21].

$$\text{TWI} = \ln(A/\tan S), \tag{2}$$

where A denotes the area of the study area in km^2, and S is the slope gradient.

To create the soil type factor map, the soil types in the research region were first identified using GIS from a site affiliated with the World Food Authority (FAO), which provides a global database with a spatial resolution of 30 s, or 1 km, for the types and characteristics of soils around the world, the extracted vector soil map was then transformed to raster format.

To create the soil map, types of soil in the research region were first identified using ArcGIS from a site

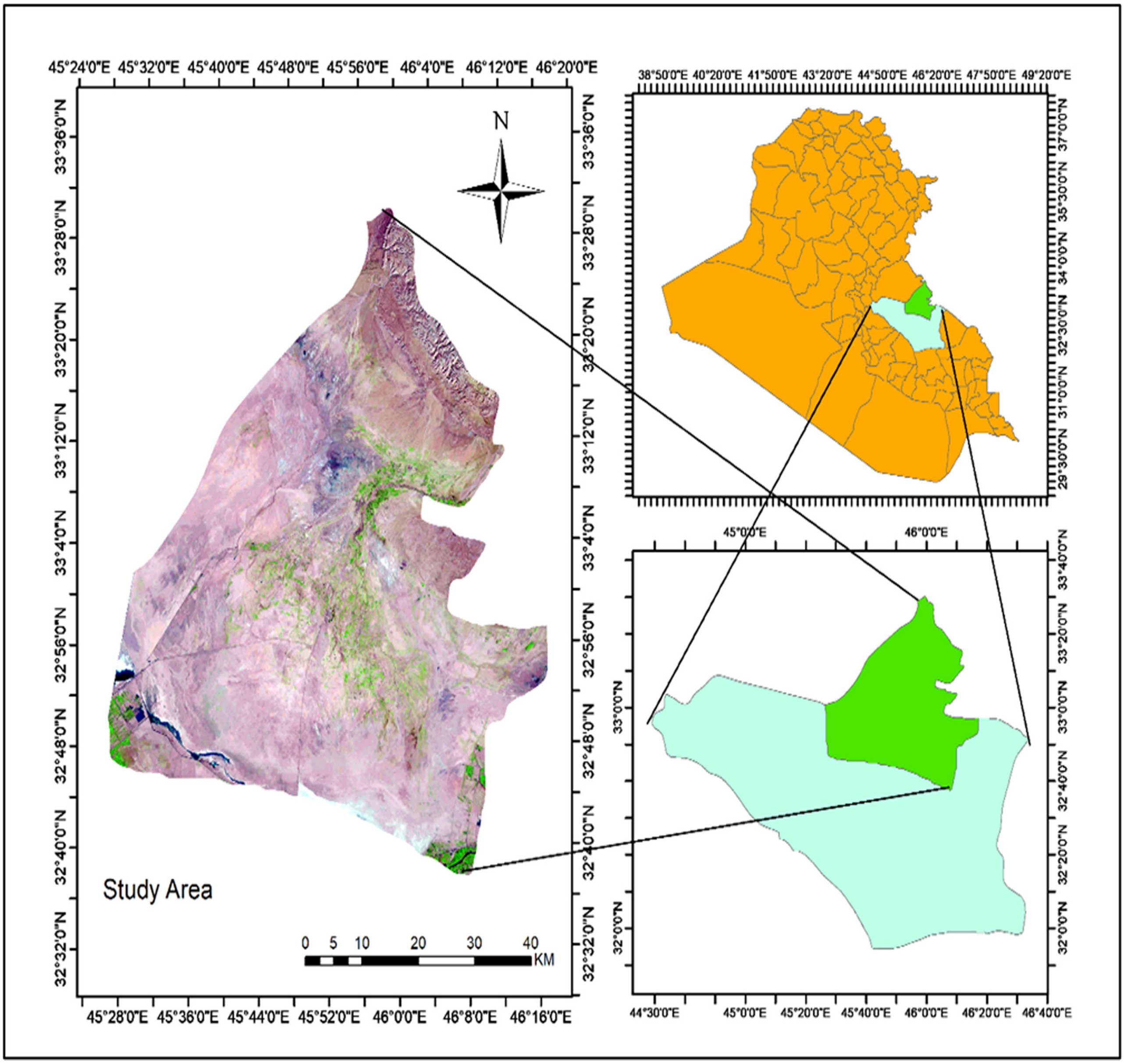

Figure 1: Topographic elevation and the study's geographic location.

Table 1: Data types and sources used for the suitability map of the study area

Data types	Data sources
STRM DEM (30 m spatial resolution) 2023	Downloaded from U.S Geologic Survey (http://earthexplorer.usgs.gov/)
Digital soil map	Downloaded from (https://www.fao.org/)
Administrative map of Iraq	Downloaded from (https://www.diva-gis.org/)

affiliated with the World Food Authority (FAO), which provides a global database with a spatial resolution of 30 s, or 1 km, for the types and characteristics of soils around the world, after being retrieved, the soil map was converted from vector to raster format.

The Spatial Analyst Tools were used to reclassify each and every raster factor map. Tools for Data Management should be reclassified and resampled in the ArcGIS environment using a single measurement scale from 1 (very low) to 5 (very high). After reclassifying all factor maps, the relative influence weights for each component were calculated using the AHP model. To construct the district's final map, the weighted overlay method was used to combine the four spatial layers in the ArcGIS environment (equation (3)) [22]:

$$\begin{aligned}&\text{Managed aquifer recharge map}\\&= W_S \times R_S + W_{SO} \times R_{SO} + W_{DD} \times R_{DD}\\&\quad + W_{TWI} \times R_{TWI},\end{aligned} \tag{3}$$

where weight slop is denoted W_S and rating slop is R_S; weight soil is W_{SO} and rating soil is R_{SO}; weight drainage density is W_D; and the rating drainage density is R_D. Weight TWI is W_{TWI} and rating TWI is R_{TWI}. The stages for the study's methodology are laid out in Figure 2.

4 Results and discussion

4.1 Slope

The slope is an essential factor in determining groundwater potential. The slope is defined as the rate of elevation change [23]. A higher degree of slope leads to velocity runoff, which results in no water infiltration and a rise in soil erosion. The result of the study indicates the variation in the slope of the study location from 0 to 56 degrees (Table 2), which is divided into five zones (Figure 3a). The high value denotes a steep slope, indicating the lowest groundwater potential. The low number, on the other hand, suggests a low slope (high groundwater potential; Figure 3b).

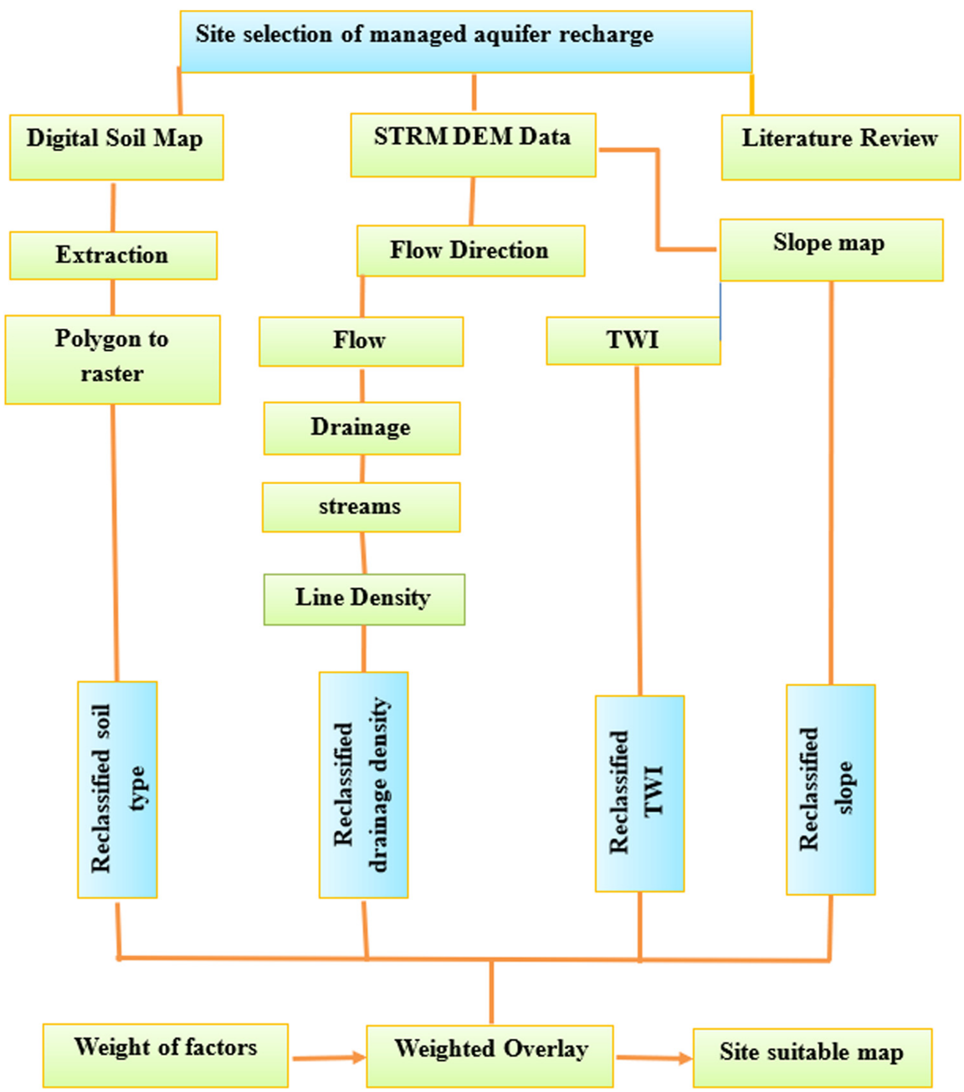

Figure 2: Flowchart site suitable map of the study area.

Table 2: Criteria and rating used in the site suitability study

Criteria	Class	Range	Rating	Weight
Slope	Very high	0–11	5	0.25
	High	11–22	4	
	Moderate	22–33	3	
	Low	33–45	2	
	Very low	45–56	1	
Soil	High	Loam	4	0.25
	Low	Clay loam	2	
Drainage density (km/km^{-2})	Very high	0.15–1.14	5	0.25
	High	1.14–2.14	4	
	Moderate	2.14–3.13	3	
	Low	3.13–4.13	2	
	Very low	4.13–5.12	1	
TWI	Very low	3.0–7.2	1	0.25
	Low	7.2–11.4	2	
	Moderate	11.4–15.6	3	
	High	15.6–19.7	4	
	Very high	19.7–23.9	5	
	Total = 1			

4.2 Soil type

Soil type is one of the main influence parameters of soil capacity to support groundwater recharge [24]. Soil is essential for water penetration into the reservoir. It is vital to understand the soil type of the research region in order to ensure water sustainability. A classified soil map of the study area was generated, which shows two major soil categories, loam and clay loam (Figure 4a). The Soil ranks are classified according to their infiltration rate, the value of rating was (2) for clay loam and (4) for loam (Figure 4b). The clay loam soil texture covers most of the study area. Loam soil has a greater priority for groundwater recharging because of its high infiltration rate [25]. Each soil data site's infiltration rate value was allocated based on the correlation provided in Table 2.

4.3 Drainage density

Drainage density has an inverse permeability function and is calculated as the sum of all stream segment lengths divided by area. Typically, drainage density is calculated by dividing the distance of the stream by the area coverage, yielding a drainage density number. Permeability is inversely proportional to drainage density [26]. A high drainage density number suggests runoff favorability and, as a result, a poor recharge groundwater potential zone (Table 2).

The result of the drainage density map appears. Generally, the values ranged from 0 to 5.12 (Figure 5a), consisting of five zones. The maximum drainage density was assigned the lowest rating value (1), while the lowest drainage density was assigned the value (5) (Figure 5b).

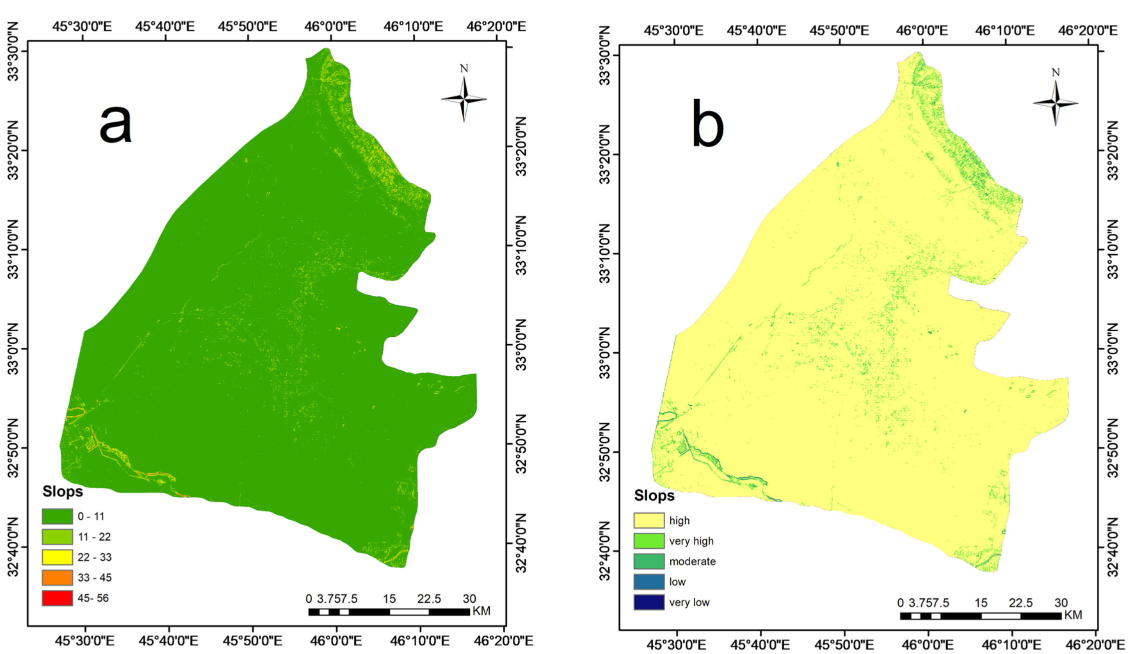

Figure 3: (a) The Slope map and (b) the rating slope of the study area.

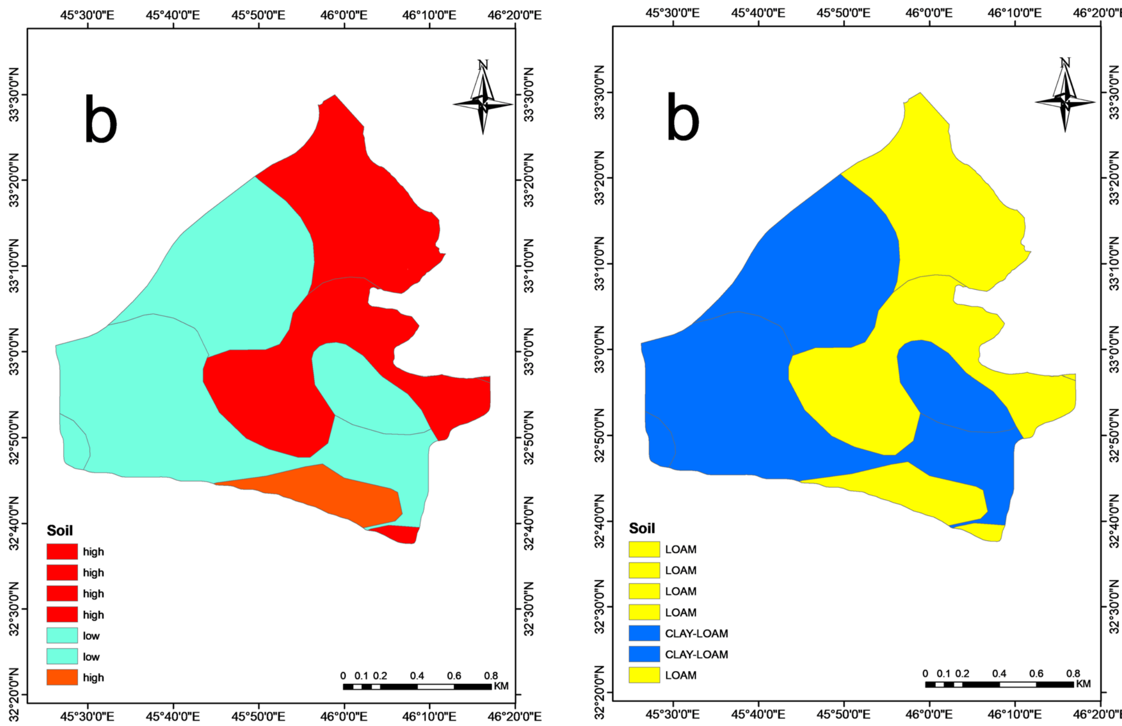

Figure 4: (a) The soil map; (b) the rating soil of the study area.

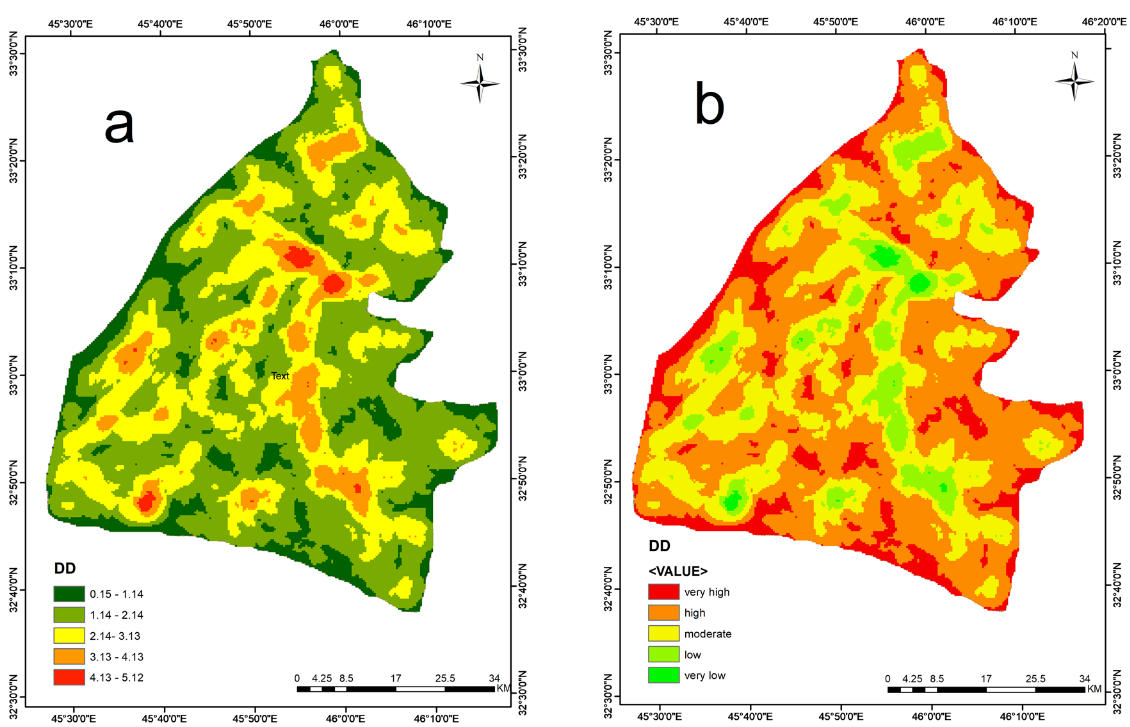

Figure 5: (a) The Drainage density; (b) the rating drainage density of the study area.

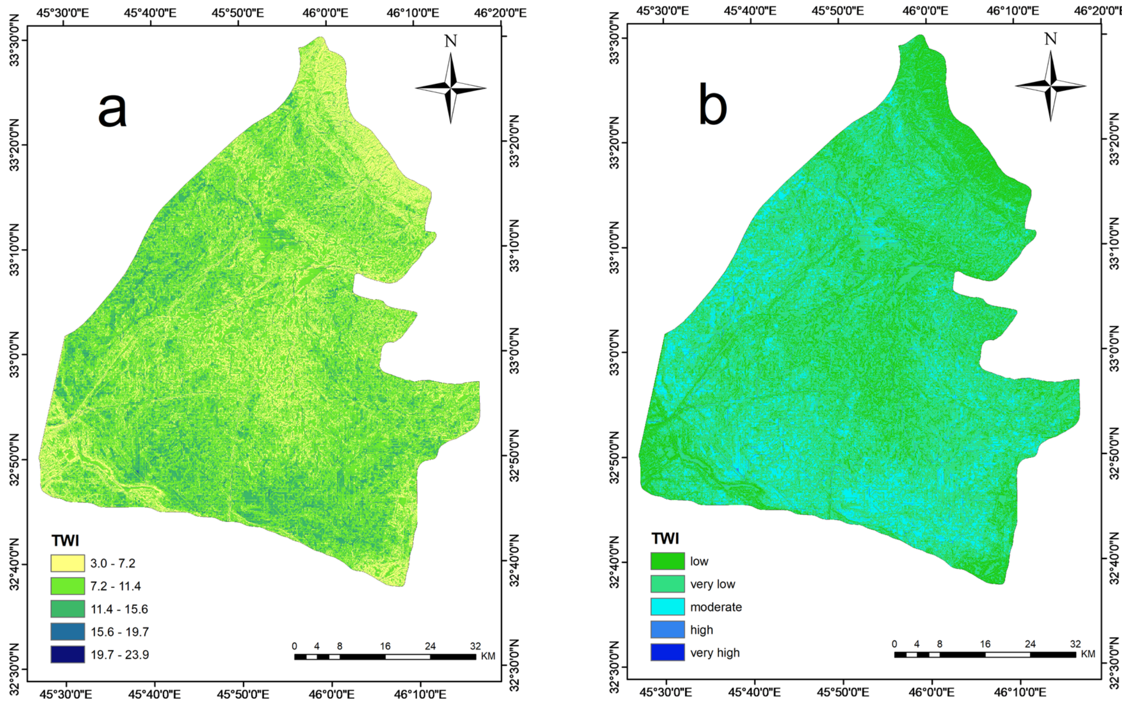

Figure 6: (a) The TWI; (b) the rating TWI of the study area.

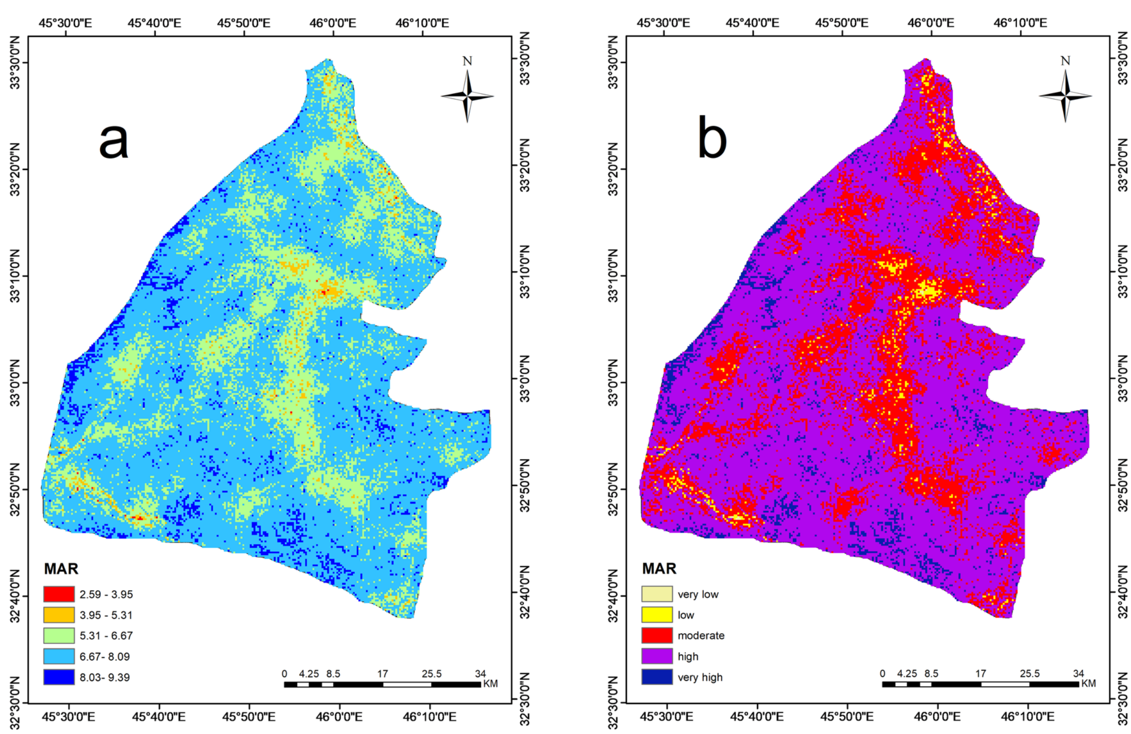

Figure 7: (a) Suitability map; (b) the rating suitability map of the study area.

Table 3: Suitability map for MAR, the area coverage, and the percentage

Site suitability	Class pixels	Area (km)	%
Very low (1)	2.59–3.98	74.888	1.82
Low (2)	3.98–5.29	145.798	11.56
Moderate (3)	5.29–6.70	1040.249	24.98
High (4)	6.70–8.11	1445.395	34.72
Very high (5)	8.11–9.39	1117.316	26.83
Total		**3823.646**	**100.00**

4.4 TWI

The TWI describes the quantity of flow accumulation at a certain location in the watershed as well as its propensity of the water to flow down the slope owing to gravity [21,27], which increases the accumulation of water flow and can also be used to describe wetness conditions in a given area [28,29]. Several studies have used the TWI to map MAR [8,28,30]. TWI values of the study area ranged between 3.0 and 23.9, as displayed in Figure 5a. TWI is classified into five sub-classes (Table 2)., which are very high (19.7–23.9), high (15.6–19.7), moderate (11.4–15.6), low (7.2–11.4), and very low (Figure 6b). The TWI is positive for aquifer recharge of groundwater [28,31].

4.5 Site suitability map for MAR

Combining the reclassified criterion maps produced the MAR suitability map (slop, soil type, drainage density, and TWI) and the AHP technique. The results show that high values indicate high suitability and more of the site's surface is appropriate for recharging techniques (Figure 7a). The site suitability was classified into five zones (Figure 7b), very good (1117.316 km^2), good (1445.395 km^2), moderate (1040.249 km^2), low (145.798 km^2), and very low (74.888 km^2) of study area (Table 3). According to the site suitability map, the results show that high values indicate high suitability and more of the site's surface is appropriate for recharging techniques.

5 Conclusions

For long-term development, particularly in dry and semi-arid areas, groundwater is a crucial supply of water. In the current investigation, remote sensing data from Landsat-8 OLI, SRTM, ALOS/PALSAR, TRMM, and GIS techniques were effectively combined; reconnaissance information for water resources was exposed, appraised, and monitored. Using many criteria, the eastern Wasit region of Iraq, which has an area of 4163.1750 km^2, was examined to identify prospective zones of suitable sites for MAR as explained below:

1. Four GIS maps are predictive slope, soil type, drainage density, and TWI by utilizing standardized and integrated data from satellite images, both radar and optical using the AHP-weighted overlay techniques.
2. The four evidentiary maps were fused using a GIS-based overlay approach for delineating suitable prospective MAR zones.
3. The appropriate site map was then divided into five categories: very high, high, moderate, low, and very low potentiality. These areas cover 26.83, 34.72, 24.98, 11.56, and 1.82% of the study area, respectively.
4. Investigating MAR is beneficial for study area decision-makers who are thinking about sustainability.

Funding information: The authors state no funding involved.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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