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The Selection of Groundwater Recharge Sites in the Arid Region of Northern Badia, Jordan, using GIS-Based Multicriteria Decision Analysis

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Abstract-This study aims to locate new groundwater recharge sites in the arid region of northern Badia, Jordan, based on specific criteria including lithology, drainage and lineament density, soil texture, slope, and rainfall. With groundwater serving as the key source of Jordanian drinking water, the use of surface water for groundwater recharge is essential in maximizing the groundwater available. Groundwater recharge sites were selected using the weighted linear combination (WLC) method with the aforementioned criteria. According to the findings, 5.064% of the region is very highly suited to groundwater recharge, 33.599% of the region is highly suited, and 3.789% of the region is moderately suited. However, 26.634% of the region is poorly suited to groundwater recharge, with a further 30.943% being very poorly suited. The significance of each criterion for groundwater recharge was identified using removal analysis, with the most significant factor being efficient groundwater management. Given this finding, big data are required in order to determine the optimal locations for groundwater recharge as part of future groundwater planning and management.

Keywords: arid region, Jordan, groundwater recharge, GIS, MCDA, WLC

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Introduction

As Sargaonkar *et al*. (2011) explains, the contamination of groundwater is extremely rare, making it a key source of potable water at present. One of the most commonly adopted approaches for consolidating groundwater resources is groundwater recharge, where underground water is refilled by other water, either in the form of natural or artificial recharge. Simmers (1997) adds that natural recharge can be localized (from surface water pond where well-defined flow channels are unavailable), indirect (surface watercourse percolation to the water table), or direct (from rain following the subtraction of interception, runoff and transpiration). As Lloyd (1986) notes, climate has a significant impact on which form of recharge primarily occurs in different regions.

Artificial recharge is widely recognized as an effective approach for the management of water resources, having been adopted in regions around the globe for a number of years. Here, surface runoff and river waters are conserved in aquifers, which are used as reservoirs. Spandre (2006) states that the utilization of artificial recharge is largely determined by the groundwater engineering and hydrogeology in question. The researcher also suggests that it is beneficial to supplement groundwater resources and reservoirs with surface waters since these waters are often naturally purified through subsurface filtration, because groundwater reservoirs do not take up land surface space, and because plant transpiration and evaporation are non-issues in this context, which is greatly beneficial in semi-arid and arid regions such as the Badia region of Jordan.

GIS (WLC and Boolean) and MCDA have been widely used for site selections in several applications such as water harvesting schemes, landfill sites, and infrastructures. Examples of these applications are found in the literature such as Janssen and Rietveld (1990), Srivastava (1996), Eastman (1997), Gupta *et al*., (1997), El-Awar *et al*. (2000), Zehtabian *et al*., (2000), Heywood *et al*. (2002), Baban and Wan-Yusof (2003), Fortes *et al*., (2005), Shatnawi (2006), Delgado *et al*. (2008), Al-Adamat (2008), Al-Adamat *et al*. (2010), Shirahatti, *et al*., (2010), Hammouri *et al*. (2014), Al-Amoush *et al*. (2016), Al-Shabeeb (2016), Al-Shabeeb *et al*. (2016), and Al-Adamat and Al-Shabeeb (2017).

The utilisation of GIS and MCDA for groundwater recharge have been explored by numerous researchers, including Krishnamurthy and Srinivas (1995), Krishnamurthy *et al*. (1996), Saraf and Choudhury (1998), Ghayoumian *et al*. (2002), Han (2003), Nouri (2003), Ghayoumian *et al*. (2007), and Al-Adamat (2012). In the current study, Jordan Northern Badia region is selected as the target region in which to identify potential groundwater recharge sites using the GIS-MCDA model.

Investigated Area

The semi-arid and arid region of northern Badia experiences an average of 50-150 mm of rainfall each year, with an average daily temperature of 25°C and 533mm daily average evaporation. Northern Badia lowest altitude is 650 m above sea level, in the southeast, with its highest altitude being 900 m above sea level, in the northwest. Badia is characterized by numerous northwest-bound valleys (wadis), which flow down the low slope (ca. 2%) between the north and south. The location of northern Badia, relative to the rest of Jordan, is illustrated in Figure 1 below.

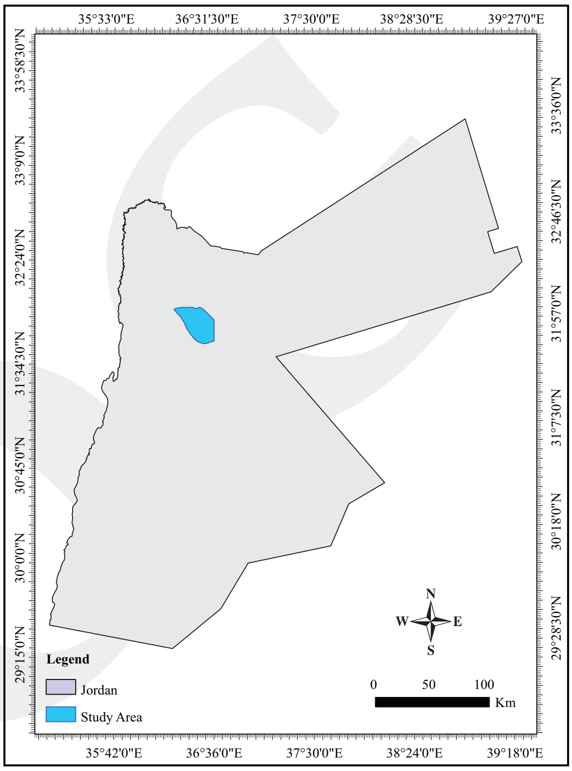

Figure 1. Location of the investigated area.

Methods

Six criteria (slope, soil texture, rainfall, drainage density, lineament density, and lithology) were selected in order to determine the most suitable groundwater recharge sites in northern Badia. As illustrated in Table 1, various data sources were used to generate the six thematic layers for this research. A digital elevation model (DEM) of the Shuttle Radar Topographic Mission (SRTM) was used to obtain the slope map, with the SRTM DEM also used to obtain the drainage density. The Royal Jordanian Geographical Centre (RJGC) provided a 1:250,000 scale lineament map used to obtain the lineament density. The Natural Resources Authority of Jordan provided a

Table 1. Datasets Used to generate Thematic Layers

Used Data	Scale/Resolution	Format	Generated Layer
Geology	1:250,000	Vector	Lithologic map
Soil	1:750,000	Vector	Soil Texture
Rainfall	1: 250,000	Vector	Rainfall map
ASTER DEM	30 m	Raster	Slope map
ASTER DEM	1:250,000	Raster	Drainage density
Lineament	1:250,000	Vector	Lineament density

1:250,000 scale lithologic map, whilst Al-Adamat *et al*. (2007) data were used to obtain rainfall and soil data.

Carver's (1991) multicriteria evaluation is assessed in this paper in order to address the research aim. The WLC approach is considered to offer benefits in terms of being more realistic, easier to use, offering greater flexibility, and having the ability to indicate the most significant spatial units of factor maps. Therefore, the WLC method is adopted in this paper for the purpose of identifying potential sites for groundwater recharge in northern Badia. Here, as Eastman (2001) explains, each of the six criterion is assigned a weight before being combined, with a suitability map obtained based on the sum of results. This can be expressed as follows:

$$Si = \Sigma\, W*R \quad \text{...} \quad (1)$$

Where:

W is the weight of the criteria
R is the rating of the criteria
Si is the suitability index

The final suitability map for groundwater recharge sites was obtained by integrating all of the thematic layers into the GIS environment. The equation representing the calculation of the suitability index for groundwater recharge is expressed as:

$$GSI=(Sw\times Sr)+ (SLw\times SLr) + (LIw\times LIr) + (DDw\times DDr) + (Rw\times Rr)+(LTw\times LTr) \quad \text{.......} \quad (2)$$

Where:

w is the weight of each criterion
r is the rating of each individual criterion class
GSI is the groundwater recharge suitability index
S is soil texture
SL is slope
LI is lineament density
DD is drainage density
R is rainfall
LT is lithology

Figure 2 below, illustrates the methodology adopted in this study:

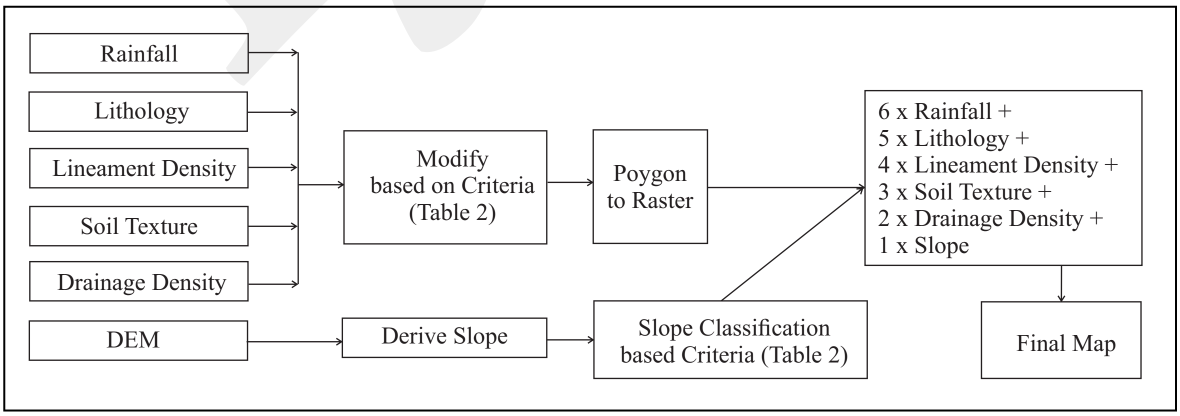

Figure 2. Methodology flowchart.

The weights and ratings of the criteria used for groundwater recharge site selection are presented in the Table 3, based on the work of Al-Shabeeb (2015).

Results and Discussion

The weights and ratings illustrated in Table 2 above are used to transform the thematic layers into a raster format, with Equation 2, and then they are used for calculation purposes. Each of the thematic layers is illustrated in Figures 3 - 8. The selection of potential groundwater recharge sites was achieved using ArcGIS WLC, with Figure 9 demonstrating the map of possible groundwater recharge sites based on the analysis, rated from very low to very high in terms of suitability.

The chosen criteria are outlined in Table 3, along with their relation to the suitability map for groundwater recharge. As illustrated in the table, annual rainfall above 300 mm would significantly improve the suitability of the chosen area as a groundwater recharge site. Furthermore, a high potential for groundwater recharge is seen in areas where alluvium and basalt are present in the lithology. Additionally, there is a high potential for groundwater recharge in areas with shallower (<5%) slopes, sandy loam, and sandy clay loam soil texture, and areas with less than 2.5 km / sq.km of both drainage and lineament densities.

As shown in Table 4, 5.064% of the selected region appears to be very highly suitable as a potential groundwater recharge site, with 33.599% of the area highly suitable and 3.789% of the region moderately suitable. However, the table

Table 2. Weights and Ratings for Site Selection

Criteria	Weight	Classes	Rating	Importance
Rainfall (mm)	6	>=500 500>R>=300 300>R>=100 <100	4 3 2 1	Rainfall determines the amount of water that falls, and thus, areas that receive more precipitation have more opportunity of infiltration than those with low rainfall. Hence, this criterion is the most important one that impacts the selection of suitable sites for groundwater recharge.
Lithology	5	Alluvium Basalt Volcano Mud flat	4 3 2 1	Lithology determines the types of materials of the zone above the water table that the infiltrated water has to pass through it from surface. Thus, it is an important criterion for identifying sites for groundwater recharge.
Slope (%)	4	<3 3-5 5-10 >10	4 3 2 1	The slope of the land surface determines the areas that have good suitability for a groundwater recharge. Flat or semiflat (low slope) areas are more suitable for groundwater recharge than high slope areas.
Lineament density (km/sq.km)	3	<=1.5 1.5-2.5 2.5-3.5 >3.5	4 3 2 1	Lineament density criterion indicates fractures and joints that serve as channels for movement of water to the groundwater. Hence, this criterion is an important character that impacts groundwater recharge.
Soil texture	2	Silty clay Sandy clay Sandy clay loam Sandy loam	1 2 3 4	Soil texture criterion plays an important role in the infiltration of surface water to groundwater aquifers. It represents the uppermost portion of the vadose zone and controls the amount of recharge.
Drainage density (km/sq.km)	1	>=0.75 0.75-1.5 1.5-2.55 <2.55	1 2 3 4	Drainage density impacts the suitability for groundwater recharge of an area, because it represents reverse function of permeability and the relationship with surface runoff.

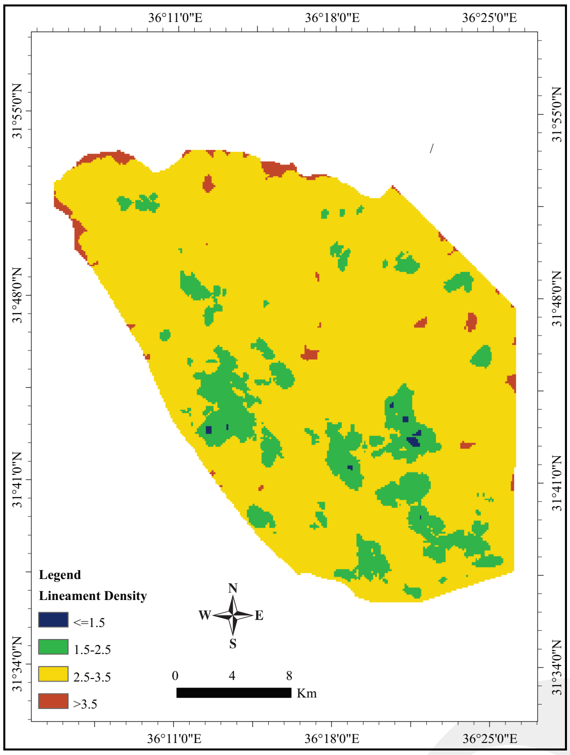

Figure 3. Lineament density.

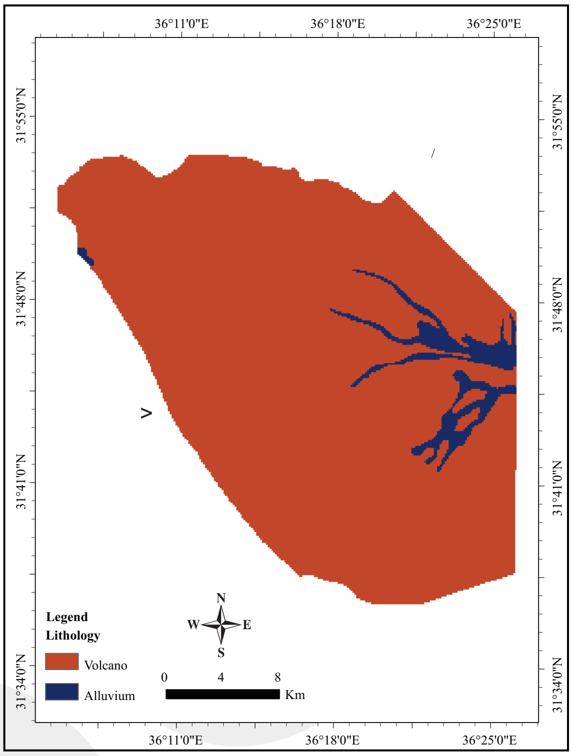

Figure 5. Lithology.

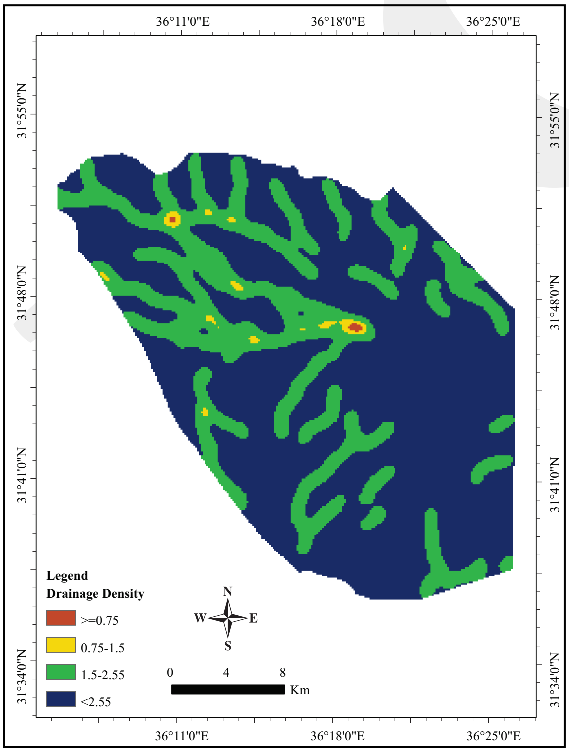

Figure 4. Drainage density.

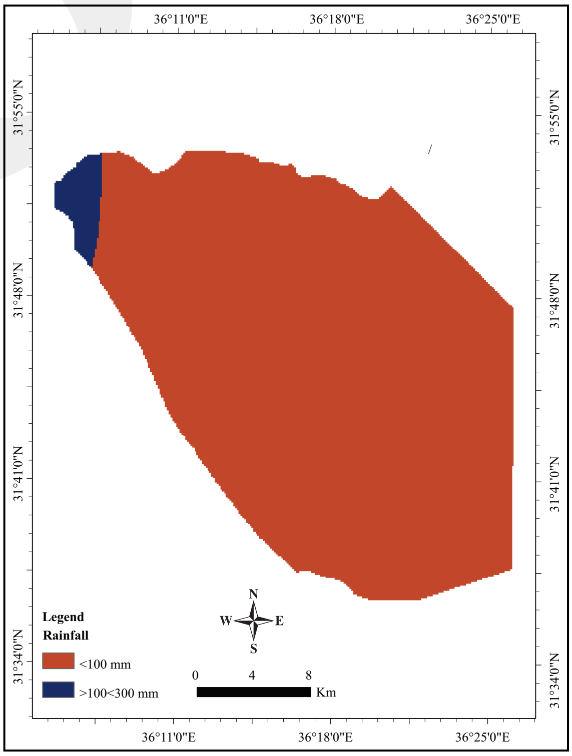

Figure 6. Rainfall (mm).

also indicates that 26.634% of the region is poorly suited to groundwater recharge, with an additional 30.943% very poorly suited as a groundwater recharge site.

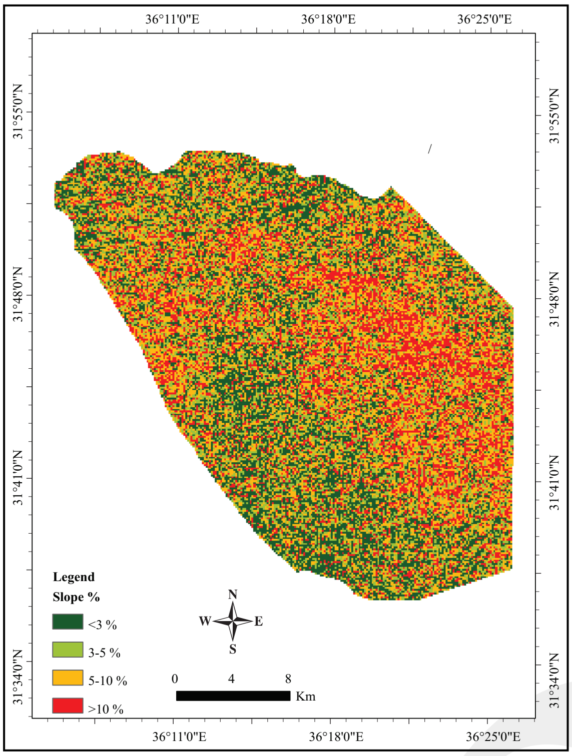

Figure 7. Slope.

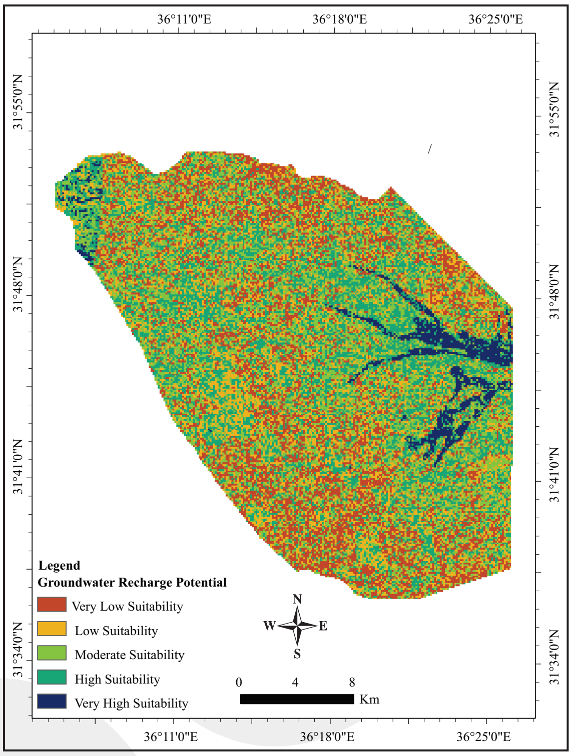

Figure 9. Groundwater recharge (without land use).

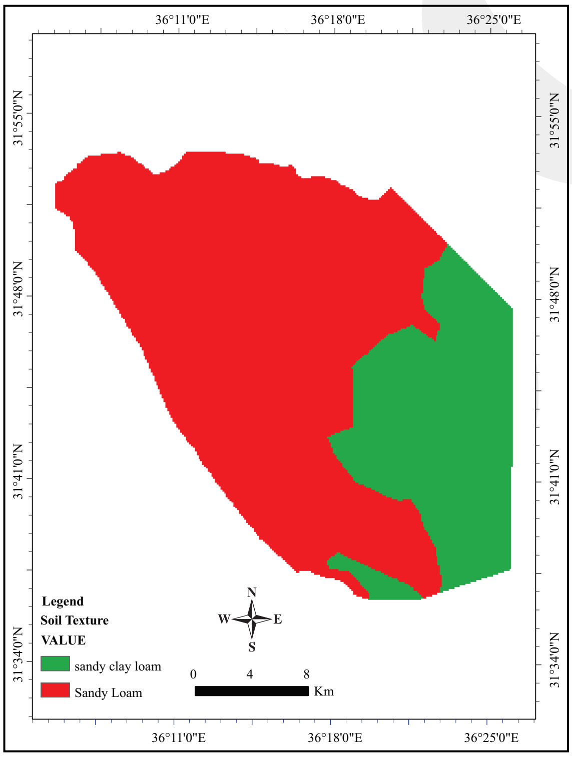

Figure 8. Soil texture.

In order to exclude unsuitable groundwater recharge sites from the results, the previous groundwater recharge suitability map (Figure 9) was incorporated with the land use map for the investigated area (Figure 10). This map was then used to analyze suitability with the inclusion of land use, as shown in Table 5. Based on the results, approximately 6.6% of the chosen region appears to be unsuitable for groundwater recharge, whilst approximately 6.5% appears to be highly to very highly suitable as a groundwater recharge site.

Sensitivity Analysis

The purpose of sensitivity analysis is to understand the degree to which the results of the groundwater recharge site analysis are impacted by the rating values and weights assigned to each of the six criteria. Therefore, sensitivity analysis helps to determine which of the criteria has the greatest impact on the results (Gogu and Dassargues, 2000). As per the work of Al-Adamat (2017) and Al-Adamat and Al-Shabbeb (2017), common approaches to sensitivity analysis at present include statistical analysis, map removal analysis, and map removal sensitivity analysis, amongst others.

Table 3. Potential Groundwater Recharge Sites based on the Six Criteria

Criteria	Groundwater Potential Zones			
	Very high Potential	**High Potential**	**Moderate Potential**	**Low Potential**
Rainfall (mm)	>=500	500>R>=300	300>R>=100	<100
Lithology	Alluvium	Basalt	Volcano	Mud flat
Slope (%)	<3	3-5	5-10	>10
Lineament density(km/sq.km)	<=1.5	1.5-2.5	2.5-3.5	>3.5
Soil texture	Sandy loam	Sandy clay loam	Sandyclay	Silty clay
Drainage density(km/sq.km)	<2.55	1.5-2.55	0.75-1.5	>=0.75

Table 4. Suitability for Groundwater Recharge (without land use)

Suitability	Area (km^2)	Area (%)
Very low	8,511,300	30.94
Low	7,362,000	26.63
Moderate	1,042,200	3.79
High	9,242,100	33.60
Very High	1,385,100	5.06

Table 5. Final Suitability for Groundwater Recharge (with land use)

Suitability	Area (km^2)	Area (%)
Unsuitable	4,349	6.61
Very low	20,904	31.79
Low	2,144	32.60
Moderate	14,758	22.44
High	2,894	4.40
Very high	1,423	2.16

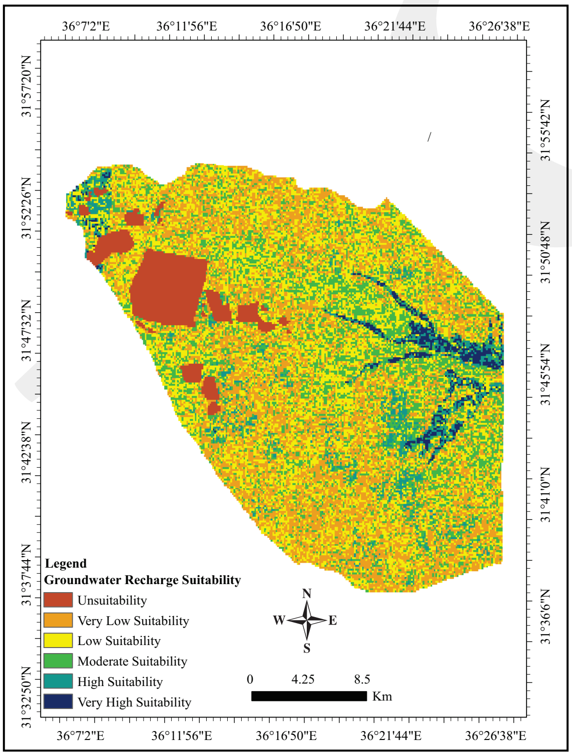

Figure 10. Final groundwater recharge map of the studied area (including land use).

Sensitivity analysis has been explored in studies published all over the globe (*e.g.*, Lodwick *et al.*, 1990; Napolitano and Fabbri, 1996; Gogu and Dassargues, 2000; Hammouri *et al.*, 2013; Al-Adamat, 2017; Al-Adamat and Al-Shabeeb, 2017) with researchers explaining that one criterion is removed during each computation of the model index. In the current study, the impact of each of the six criteria on the results is determined using map removal analysis.

The significance of each criterion is illustrated in Table 6. Based on the results of the analysis, the most to the least influential criteria were soil texture, drainage density, and rainfall, at a mean value of 36.80, 36.48, and 34.03, respectively; followed by lineament density, slope, and lithology, with respective mean scores of 33.82, 30.10, and 29.72. The results of the map removal analysis are illustrated in Figure 11.

Table 6. Map Removal Sensitivity Analysis

Criteria	MIN	MAX	MEAN	SD
Slope	24	46	30.1	2.47
Soil texture	26	58	36.8	5.27
Lithology	18	43	29.72	4.61
Rainfall	22	54	34.03	5.11
Lineament density	25	56	33.82	5.12
Drainage density	25	58	36.48	5.106

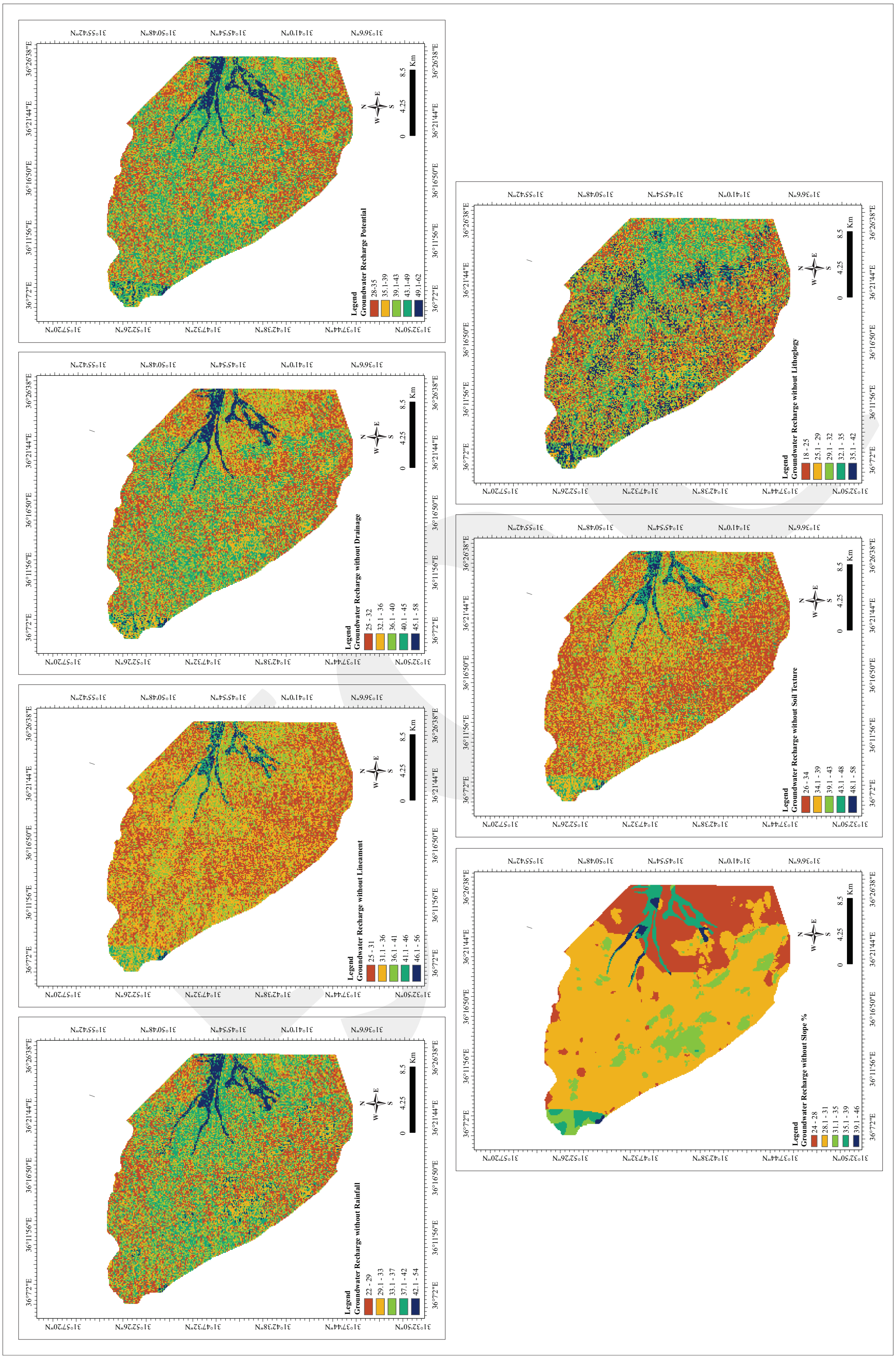

Figure 11. Removal sensitivity analysis - sensitivity maps.

Conclusion and Recommendations

This study demonstrates the value of GIS in the management of groundwater resources and selection of potential groundwater recharge sites. Some of the benefits of GIS include its ability to analyze and to store large quantities of data in various formats. The chosen studied area of northern Badia was examined using GIS-based multicriteria analysis using the WLC method in order to identify potential sites for groundwater recharge in this semi-arid and arid area of Jordan. GIS was used to prepare, classify, weight, and integrate the six thematic layers (soil texture, slope, rainfall, lithology, lineament density, and drainage density) used in this study.

The findings of this research support future planning in the field of groundwater recharge and groundwater resource management, with the map demonstrating the most suitable sites for groundwater recharge. According to the results, over 33% of the selected region is highly suited to groundwater recharge, with over 5% highly suited and over 3% moderately well suited. The analysis also illustrates the areas in which there is low and very low suitability for groundwater recharge, representing just over 26% and 30% of the selected region, respectively.

Sensitivity analysis is used to test the validity of the measures, with soil texture, drainage density and rainfall found to be the most influential factors in selecting a suitable groundwater recharge site, followed by lineament density, slope, and lithology. It is recommended that the results of this research, along with the methods adopted, are utilized for the purpose of future groundwater resource management and for the selection of suitable sites for groundwater recharge projects in Jordan northern Badia region.

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