The Application of the Analytic Hierarchy Process and GIS to Map Suitable Rainwater Harvesting Sites in (Semi-) Arid Regions in Jordan

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Abstract
The current study is based on the evaluation of the assessment of rainwater harvesting (RWH) in (semi- arid) regions. Where, this study aimed to assess the implementation of RWH by developing a methodology that can be easily applied to identify rainwater harvesting locations in Hasa Basin in southwest Jordan, through integration between the Multiple Criteria Decision Models (MCDM) using an analytic hierarchy process (AHP), and Geographic Information System (GIS). The main factors considered to achieve the aim of the study were rainfall intensity, runoff, slope, flood susceptibility, soil texture, geology, land use/ cover (LULC), elevation, rivers, faults, settlement centers, roads, wells. These were reclassified and weighted to map the levels of rainwater harvesting in the study area. Rainwater harvesting suitable sites map obtained for the study area showed that areas with high and very high suitability formed, respectively, about 11.14% and 1.17%, while areas with low and very low suitability, in contrast, constituted about 46.09% and 9.68 %, respectively, of the total area of the study area.

Keywords: AHP, GIS, Hasa Basin, MCDM, RWH

1. Introduction

The arid and semi-arid regions of the world suffer from an increasing shortage of available water resources at the present time. As the scarcity of rain affects soil productivity and development in its various sectors, especially in regions that are overwhelmed by severe drought conditions. Thus, water in Jordan acquires special importance due to its scarcity and limitations, and the irregularity of its temporal and spatial distribution. As a result of increasing population growth, and the high pace of economic and social development, the problem of water scarcity is exacerbated as a logical consequence of the increasing demand for water for various needs. Hence, RWH is one of the most important methods to store water when rainstorms occur, to reduce water deficit and high demand during the long dry months in Jordan [1]. The RWH can also be considered one of the most efficient ways to save water both environmentally and financially, as it contributes to adding realistic solutions to the problem of water scarcity and depletion of aquifers [2] [3] [4] [5] [6] and [7]. Moreover, RWH can be managed in several ways to be used for various purposes in groundwater recharge, flood risk reduction, soil moisture improvement, irrigation, and grazing reserves [8] [9] and [10]. Adequate selection of sites for RWH potential requires the consideration of several criteria, including hydrology, climatic characteristics, topography, and soil parameters, in order to improve water availability, especially in arid regions [11] and [12].

The MCDM and GIS tools are used to analyze land suitability evaluation for a specific use such as rainwater harvesting. They are also a prerequisite for land-use planning and development [13]. The aim of integrating MCDM with GIS is to provide more flexible and accurate options to decision-makers to evaluate the significant factors affecting the selection of potential sites for RWH [14]. Hence, one of the important functions of GIS is spatial decision-making, based on the maps produced in integration with AHP, where the map becomes the focus for setting priorities for decision criteria to benefit in improving the availability of water resources. Moreover, the MCDM aim to develop creative solutions in identifying the areas of most suitable RWH sites by integrating them into the GIS environment [15] [16] [17] and [18]. In addition, the GIS-MCDM model is used to prepare maps that represent proposals in support of spatial decision-making regarding the most suitable rainwater

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harvesting sites, based on the development of a number of criteria that constitute the most influential factors to determine the appropriateness of the land characteristics for the construction of RWH projects [19] [20] [21] [22] [23] [24] and [25]. The current study aims to develop a model using GIS based on AHP to create an RWH potential area map that contributes to the planning and management of water resources in Hasa Basin in southwest Jordan.

2. Materials and Methods

The selection of suitable RWH areas is related to several physical and anthropogenic factors. Rainwater harvesting projects contribute to improving the water situation in semi-arid and arid regions in Jordan, in addition to their positive socio-economic and environmental consequences.

2.1 Study Area

The study area is located in the southwest region of Jordan and geographically lies between 35°29′30″ E and 36°26′18″ E longitude and 30°33′17″ N and 31°03′16″ N latitude covering an area of 2632.6 km², representing a percentage of 2.95 % of the total area of Jordan. The maximum length of the basin is 98 km from southeast to northwest toward the Dead Sea, while the maximum width extends for 42 km from north to south **(Figure 1**).

2.2 Materials

The long-term (1990-2021) climatic data used in this assessment constitute the daily, monthly, and annual rates of rainfall for 10 climatic stations. Depending on the climatic records of the Meteorological Department, and the data of the Ministry of Water and Irrigation in Jordan (**Table 1**). Also, this work is based on two obtained remote sensing datasets: (i) Landsat-8 surface reflectance data freely available from USGS (*http://www.usgs.gov/*) during the period 2020; and (ii) ASTER DEM (*https://asterweb.jpl.nasa.gov/gdem.asp*) data freely available from NASA. It was used to determine the location of the study area and its topographical characteristics such as elevation and slope, and types of LULC for the study area. The soil texture data were obtained from the soil survey records of the Jordanian Ministry of Agriculture for the period from 1993 – 2020. It is worth mentioning also that the spline interpolation method in GIS has been selected because it is the most appropriate one for studies involving a small number of cases [26] and [27]. **Table 2** shows details of the data and data sources.

2.3 Potential RWH System Selecting

In this paper, the AHP and GIS Modeling were used to identify RWH sites in Hasa Basin. This method consists of a weighting of a number of factors adopted by comparison, as well as a pair of factors that may control RWH in this basin. The current study relied on 13 factors in order to determine suitable sites for RWH: rainfall intensity, runoff, slope, flood susceptibility, soil texture, geology, LULC, elevation, rivers, faults, settlement centers, roads, and wells. The set of RWH factors is related to the purpose of this study, and the 13 factors or criteria were chosen to increase accuracy in determining suitable water harvesting sites.

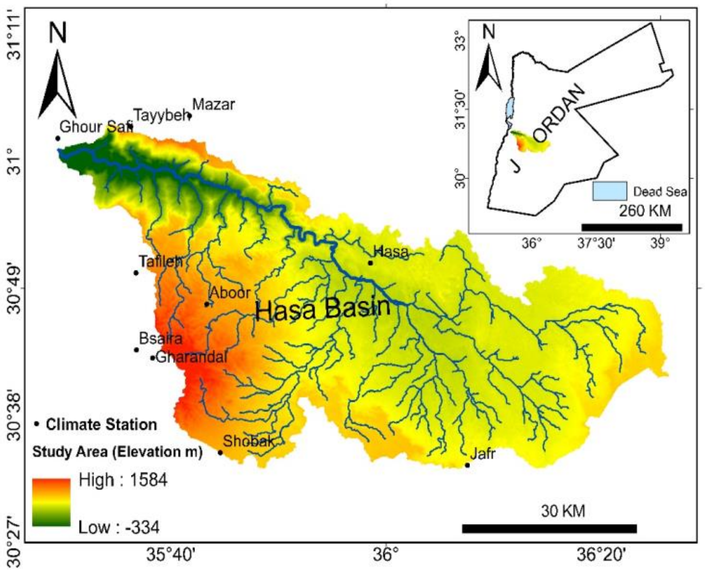

Figure 1: The location of the study area

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Table 1: List of climatic stations used in this study

Climate Station	Lat (N)	Long (E)	Ele (m)	Climate Station	Lat (N)	Long (E)	Ele (m)
South Mazar	31°03'51"	35°41'41"	1230	Aboor	30°47'36"	35°43'18"	1170
Hasa	30°51'15"	35°58'27"	860	Shobak	30°31'11"	35°32'24"	1420
Bsaira	30°43'47"	35°36'50"	1170	Jafr	30°18'47"	36°10'46"	850
Tafiela	30°50'20"	35°36'46"	1000	Ghour Safi	31°02'01"	35°29'22"	(-340)
Gharandal	30°42'52"	35°38'18"	1270	Tayybeh	31°03'	35°36'20"	1050

Table 2: Data types and sources

Data Type	Year	Resolution/Scale	Source
Landsat-8	2020	30 m	http://www.usgs.gov/
ASTER DEM	2020	30 m	https://asterweb.jpl.nasa.gov/gdem.asp
Soil Map	1993	1:50000	Ministry of Agriculture, Jordan
Geology Map	2021	1:100000	Ministry of Agriculture, Jordan
Climate Data	1990-2021	Monthly / Daily Data	Jordan Meteorological Department

2.3.1Rainfall intensity

The amount and distribution of rainfall are pivotal factors in determining a suitable RWH site. In the study area, the maximum 24-hour precipitation recorded in ten stations representing the study area is used to determine rainfall intensity. The rainfall intensity in the study area ranged from 29.7 to 144.1 mm/hour.

2.3.2 Runoff

The study relied on the Soil Conservation Service (SCS)- Curve Number (CN) model [28] and [29]. There are a number of empirical methods for Runoff estimation. The most commonly and widely used one is the SCS-CNs Invented by United States Department of Agriculture (USDA) to estimate surface runoff. This method is popular, flexible, and simple to use. The equation for surface runoff is given by:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}$$

Equation 1

Where: Q = Accumulated runoff or rainfall excess in mm

P = The rainfall mm

Ia = Initial abstraction in mm

S = Potential maximum retention in mm.

The US Soil Conservation Service has found by experience that:

$$Ia = 0.2S$$

Equation 2

The term S is given by:

$$S = \frac{25400}{CN} - 254$$

Equation 3

Where: CN is the Curve Number for study area conditions. Some modifications were done, and now Ia = 0.2S". And the equation for discharge can now be written as:

$$Q = \frac{(P - 0.2S)^2}{(P + S - 0.2S)}$$

Equation 4

2.3.3 Slope

The degree of slope is also an important factor in choosing an RWH site, and RWH systems in a location with a slope of less than 2° are usually chosen. The slopes ranged from (0 to 70.2°) in the study area.

2.3.4 Flood susceptibility

In this paper, we adopt AHP method and GIS modeling for the detection of flood hazard-prone zones. This method consists of a weighting of the factors adopted by comparing a pair of factors to control floods in this area. The main factors considered for the measurement of flood susceptibility were slope, rainfall intensity, runoff, elevation, and LULC, which were reclassified and weighted for mapping the levels of flood hazards in the study area. Each factor/criterion was weighted and assigned a rank or score by using the pairwise comparison method for making a decision about the severity of the flood. Consequently, flood hazard areas could be categorized into five risk levels, namely very high, high, moderate, low, and very low. A standard scale of 1-9 according to [30] system was used to determine the degree of impact, with a value of 9 indicating a higher degree of risk. To calculate the weights of factors, each value must be converted to in the table of the comparison matrix to a ratio of the sum per column. Then the weight of factors is the mean of each row of the standardized matrix.

2.3.5 Soil texture

Soil is an important factor in determining the RWH site. Where, the soil texture also controls water runoff, and the aquifer system, and manipulates the rate of percolation, and permeability levels. Soil texture affects the water content and ability of soils to retain water on the surface and not penetrate down. This is because texture controls the nature of soil pores. Thus, an increase in the possibility of harvested water is the result. Soil texture can be arranged in order of importance according to suitability level of RWH into silty clay loam, clay loam, silty clay, sandy clay loam, sandy, respectively.

2.3.6 Geology

The geological structure of the region is an additional main factor in determining the potential of the RWH site. Also, rock texture determines the surface hardness and its suitability as an RWH site. In addition, the stability of the slopes and their readiness for a landslide risk reflect the geological structure and the slope of the rock layers in relation to the surface slope, as well as the faults which may affect the body of the water harvesting system and water retention. The geological structure can be arranged according to the importance in determining the suitability level of the RWH to marl limestone, marl silt loam, limestone marl chalk, chert-limestone, sand-limestone, sandstone gravel dolomite, respectively.

2.3.7 LULC

LULC changes are considered critical factors that affect the selection of the RWH sites in the study area. This is because LULC plays an important role in the runoff, and the possibility of storing water [31].

2.3.8 Elevation

High-resolution DEMs are commonly used in RWH systems modeling because of their indirect effect on the amount of rainfall. Indeed, runoff, slope, LULC, and others are related to elevation. The elevation ranged from (-334m) below mean sea level (MSL) to (1584 m) above MSL in the study area.

2.3.9 Rivers

Rivers are linked to the possibility of water runoff through valleys, and then collecting and accumulating it, and thus the possibility of RWH. Thus, they determine the amount of water that can be accumulated cumulatively towards the main channel and the possibility of RWH.

2.3.10 Faults

In order to improve water storage through the establishment of RWH systems, fault lines must be taken into consideration by determining a safe distance to ensure that running water is not lost through the fault cracks.

2.3.11 Settlement Centers

It is preferable to exclude settlement centers and urban areas when making a spatial decision related to choosing the most suitable sites for the establishment RWH systems, as they are considered among the spatial determinants that are excluded for environmental and economic reasons.

2.3.12 Roads

As in the case of Settlement Centers, roads are excluded when making the spatial decision regarding the selection of the most suitable sites for setting up RWH systems for economic reasons.

2.3.13 Wells

Wells are usually built for the purposes of providing water to the population or agriculture or recharging groundwater, and therefore, it is preferable to take a spatial decision to establish an RWH system away from wells, for reasons related to maintaining the storage capacity of the RWH system. In addition, this helps to protect groundwater from sediment leakage or any other technical problem.

2.4 AHP Modeling Approaches

The AHP is considered one of the important methods in the decision-making process, where the selected factors are weighed through the pairwise comparison matrix based on the relative importance scale [17] [23] and [32]. As mentioned above, the main factors considered in this study were rainfall intensity, runoff, slope, flood susceptibility, soil texture, geology, LULC, elevation, rivers, faults, settlement centers, roads, and wells. The AHP process may be subdivided into three steps: standardization, weight assignment, and weighted linear combination.

2.4.1 MCDM mapping

The MCDM is used to infer the effect of a series of factors after they are arranged according to their importance in the possibility of water harvesting, as weights are given accordingly, and this depends on the researchers' vision in making spatial decision [33] [34] [35] [36] and [37] have used the methods processed by Malczewski [15]. when calculating weights in MCDM. The AHP developed by [30] and [38], "is one of the common methods of the multi-criteria methods". It is based on the integration and aggregation of the weights chosen for the criteria of multiple levels of the hierarchy. The weights and ranks of each factor were determined after making the pairwise comparison using the rating scale.

2.4.2 Pairwise comparison matrix

Pairwise comparison of the approved factors in the application of the AHP requires the development of a pairwise comparison matrix between the 13 factors affecting potential RWH sites, and this depends on the importance of each factor in the occurrence of RWH. These factors include rainfall intensity, runoff, slope, flood susceptibility, soil texture, geology, LULC, elevation, rivers, faults, settlement centers, roads, and wells. The pairwise comparison of each pair of elements in each level is compared with respect to the corresponding elements in the level above them, and this is done in terms of their importance. The comparisons can then be represented by multiple square matrices [39] as follows:

$$\mathrm{C} = (\mathrm{Cij})\mathrm{nxn}$$

Equation 5

Where C is the Consistency ratio to both factors i and j, with each matrix of order n. The representation of matrices that have reciprocal properties [40], is done by:

$$\mathrm{C} = \left(\frac{1}{\mathrm{Cij}}\right)\mathrm{nxn}$$

Equation 6

When you're done comparing, a weight value is assigned to the factor that has the highest importance in the pair. As for the lowest important factor in the pair, a reciprocal of the value will be assigned to it. Normalization followed by the averaging of the weights is then done to obtain the relative weight for each of the factors in the hierarchical model [40].

Each element in the matrix will be divided by the sum of its columns [41] to get the normalized matrix. Moreover, the weights of all factors in the hierarchical model were based on the researcher's vision, and by referring to previous studies within the same field, pairwise comparisons and ranking of factors were done. In analyzing suitable RWH sites, rainfall intensity was considered the most influential factor, being highly sensitive to RWH suitable sites. In contrast, wells were considered less sensitive to contributing to RWH suitable sites. The values in each cell represent the scale of relative importance for the given paired factors. The diagonal has a value of "1" throughout because the diagonal represents factors being compared to themselves with a scale of "1" (equal importance). On the lower diagonal, the values of the scale are infractions because the factors are being paired in the reverse order and the scale of relative importance is given as the reciprocal of the upper diagonal pairwise comparisons [42]. Hence, in order to identify suitable RWH sites, factors have been ranked as follows, rainfall intensity, Rivers, runoff, slope, faults, flood susceptibility, soil texture, settlement centers, geology, LULC, roads, elevation, and wells.

To calculate the weights of each factor, we need to convert each value of the comparison matrix into a percentage of the sum per column. Then, the weight of each factor is calculated as the average of each row of the standardized matrix. **Table 3** represents the AHP pairwise comparison matrix.

2.4.3 Consistency analysis

In the AHP, pairwise comparisons in a judgment matrix are considered adequately consistent if the corresponding consistency ratio (CR) is less than 10% [40]. First, the consistency index (CI) needs to be estimated. This is done by adding the columns in the judgment matrix and multiplying the resulting vector by the vector of priorities (i.e., the approximated eigenvector) obtained earlier. This yields an approximation of the maximum Eigen value, denoted by λmax [40]. Then, the CI value is calculated by using the formula:

$$CI = \frac{\lambda av - \mathrm{n}}{\mathrm{n} - 1}$$

Equation 7

Where λmax is calculated using the formula:

$$\lambda\mathrm{max} = \sum_{i=0}^{n} (Xij) \times (\mathrm{Wij})$$

Equation 8

Next, the consistency ratio CR is calculated by using the formula:

$$\mathrm{CR} = \left(\frac{\mathrm{CI}}{\mathrm{RI}}\right) \times 100$$

Equation 9

Where RI refers to the mean of an Index of Consistency; the matrix Order and CI refer to the Index of Consistency as expressed. A randomly generated pairwise comparison matrix is used to obtain the random consistency index, RI. The values of RI for matrices of order 1 to 15 [30] and [43]. The RI value in this study was 1.58, as defined by Saaty [38]. If λav is the average value of λ; 'n' is the matrix sequence. The CR is a ratio of the random index to the matrix consistency index. The value from 0 to 1.

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A CR of 0.1 or less is considered a respectable level, and over 0.1 implies revision, required because the individual factor ratings are not being handled uniformly [15]. When these approximations are applied to the previous judgment matrix, it can be verified that the following are derived factors: λav = 13.41; CI = 0.034, and CR =0.021.

Once the weighting is done, the different factors adopted and the coherence ratio values are acceptable: CR = 0.023. The superposition of the 13 input factors adopted will be carried out under ArcGIS software 10.4.1 according to the following equation:

$$\begin{aligned}\text{RWH sites} = & (0.188 * \text{ rainfall intensity}) \\ & + (0.156 * \text{rivers}) \\ & + (0.156 * \text{runoff}) \\ & + (0.126 * \text{ slope}) \\ & + (0.097 * \text{ faults}) \\ & + (0.071 * \text{ flood susceptibility}) \\ & + (0.049 * \text{soil texture}) \\ & + (0.034 * \text{settlement centers}) \\ & + (0.034 * \text{ geology}) \\ & + (0.025 * \text{LULC}) \\ & + (0.025 * \text{ roads}) \\ & + (0.02 * \text{ elevation}) \\ & + (0.02 * \text{ wells})\end{aligned}$$

Equation 10

2.4.4 Sensitivity analysis

A sensitivity analysis was performed to assess the extent of the change caused by the impact of criteria weights on RWH potential site selection, where the Parameter Sensitivity Evaluation was accomplished by applying different weights of criteria for spatial decision making. The sensitivity of the factors indicates the change in the appropriateness of establishing RWH projects as: a. The importance of a factor or combination of factors in the site selection process for RWH; B. Determining the levels of uncertainty in the different thematic maps, and determining the measurements required for a high-accuracy test to ensure high accuracy in the RWH Model; C. Sensitivity analysis was performed to help identify spatial maps that are critical for accurate determination of spatial extensions and their appropriateness to RWH; this was achieved by evaluating the effect of changes in the spatial extent (Special Extent) by changing the weights specified for the set of factors in the previous criteria table. The degree of fit and the true extent of the variance of weights were also checked using the Pairwise Comparison Method and then reformulated for each pair of factors to determine the most important factor; this method depends on changing the weights specified for each criterion in each group.

Table 3: AHP matrix and factors weight

Factors	Rainfall Intensity	Rivers	Runoff	Slope	Faults	Flood Susceptibility	soil texture	Settlement Centers	Geology	LULC	Roads	Elevation	Wells	Factors Weight
Rainfall Intensity	1	1	1	2	3	4	5	6	6	7	7	8	8	0.188
Rivers	1	1	1	1	2	3	4	5	5	6	6	7	7	0.156
Runoff	1	1	1	1	2	3	4	5	5	6	6	7	7	0.156
Slope	1/2	1	1	1	1	2	3	4	4	5	5	6	6	0.126
Faults	1/3	1/2	1/2	1	1	1	2	3	3	4	4	5	5	0.097
Flood Susceptibility	1/4	1/3	1/3	1/2	1	1	1	2	2	3	3	4	4	0.071
soil texture	1/5	1/4	1/4	1/3	1/2	1	1	1	1	2	2	3	3	0.049
Settlement Centers	1/6	1/5	1/5	1/4	1/3	1/2	1	1	1	1	1	2	2	0.034
Geology	1/6	1/5	1/5	1/4	1/3	1/2	1	1	1	1	1	2	2	0.034
LULC	1/7	1/6	1/6	1/5	1/4	1/3	1/2	1	1	1	1	1	1	0.025
Roads	1/7	1/6	1/6	1/5	1/4	1/3	1/2	1	1	1	1	1	1	0.025
Elevation	1/8	1/7	1/7	1/6	1/5	1/4	1/3	1/2	1/2	1	1	1	1	0.020
Wells	1/8	1/7	1/7	1/6	1/5	1/4	1/3	1/2	1/2	1	1	1	1	0.020

3. Results and Discussion

After the factors of RWH are compared with each other by developing a comparison matrix, they are compared regarding the importance of one with respect to another and accordingly given a rating as per Saaty's scale.

3.1 Reclassification of Suitable RWH Sites Contributing Factors

The present study was conducted to determine suitable RWH sites in Hasa Basin. The model applied in this study allows for determining zones sensitive to the suitability of RWH sites in the study area. Based on the sensitivity classes of the factors that may control RWH sites, we have established the reclassification factors maps for the suitability of RWH sites (**Figure 2**).

3.2 Weighting of Suitable RWH Sites Contributing Factors

The weighing process in MCDM is subject to the researcher's decision as there are different methods available to determine weights, but these weights must be credible. All RWH contributing factors were classified into five categories that represent the degree of the potential scale of that category on the possibility of RWH within the same factor. A standard scale of 1-9, according to the [30] and [38] system, was used to determine the degree of impact, with a value of 9 indicating a higher degree of importance. Referring to the above, these verbal judgments are based on a good expert knowledge of the field and the importance of each factor in RWH. To calculate the weights of each factor, we need to convert each value of the comparison matrix, to a percentage of the sum per column. Then the weight of each factor is calculated as the average of each row of the standardized matrix. **Table 4** indicates the weights of the factors, the percentage of weights for each factor, the suitable levels of RWH, and the classification of factors.

3.3 Suitability of RWH Sites Contributing Factors

Suitable classes were assigned to the 13 selected factors. Then, the AHP pairwise comparison matrix was constructed based on the preferences of each factor relative to the others. As input, it takes pairwise comparisons of the factors and produces their relative weights as output. All RWH contributing factors were classified into five categories that represent the degree of the suitable scale of that category on the possibility of RWH, in order to create a weighting map for 13 factors. Moreover, suitable RWH sites are classified into five suitable levels according to the severity of RWH. Depending on the areas of RWH suitable levels, the area with high and very high levels of suitability for rainfall intensity made up about 36% of the total area. Meanwhile, areas with high and very high levels of suitability for runoff represented about 26% of the total area. Also, areas on slopes that are less than 2 degrees were taken as very high suitable levels and constituted 8.7% of the total area. Meanwhile, high and very high levels of suitability for faults buffer zones represented about 85% of the total area. As can be seen from the spatial distribution of the roads buffer zone, 3.5 % and 83.5 % of the area were found to have, respectively, high and very high suitability for RWH sites.

Table 4: Classification and Weighting of Factors

Factor	Domain	Suitable Level	Normalized Weight (%)
Rainfall Intensity(mm)	110 – 144.1	Very high	18.8
	90-110	High	
	70-90	Moderate	
	50-70	Low	
	29.7-50	Very low	
Rivers (Buffer Zone m)	0-100	Very high	15.6
	100-200	High	
	200-300	Moderate	
	300-400	Low	
	Other Area	Very low	
Runoff (mm)	24-29.7	Very high	15.6
	19-24	High	
	14-19	Moderate	
	9-14	Low	
	1.2-9	Very low	
Slope(Degree)	0-2	Very high	12.6
	2-5	High	
	5-10	Moderate	

	10-15	Low	
	15-70.2	Very low	
Faults (Buffer Zone m)	Other Area	Very high	9.7
	700-800	High	
	600-700	Moderate	
	500-600	Low	
	0-500	Very low	
Flood Susceptibility (Level)	8-10	Very high	7.1
	6-8	High	
	5-6	Moderate	
	4-5	Low	
	2-4	Very low	
Soil texture	Silty Clay Loam	Very high	4.9
	Clay Loam	High	
	Silty Clay	Moderate	
	Sandy Clay Loam	Low	
	Sandy	Very low	
Settlement Centers (Buffer Zone m)	Other Area	Very high	3.4
	750-1000	High	
	500-750	Moderate	
	250-500	Low	
	0-250	Very low	
Geology	Marl, Limestone	Very high	3.4
	Marl, Silt, Loam	High	
	Limestone, Marl, Chalk	Moderate	
	Chert-Limestone, Sand-Limestone	Low	
	Sandstone,Gravel, Dolomite	Very low	
LULC	Pastures, Bare Lands	Very high	2.5
	Agricultural Lands, Wet Mudflat	High	
	Rocky Lands	Moderate	
	Deposits	Low	
	Urban Fabric, Forests	Very low	
Roads (Buffer Zone m)	Other Area	Very high	2.5
	750-1000	High	
	500-750	Moderate	
	250-500	Low	
	0-250	Very low	
Elevation (m)	(-334 -300	Very high	2
	300-600	High	
	600-900	Moderate	
	900-1200	Low	
	1200-1580	Very low	
Wells (Buffer Zone m)	Other Area	Very high	2
	1500-2000	High	
	1000-1500	Moderate	
	500-1000	Low	
	0-500	Very low	
Sum			100

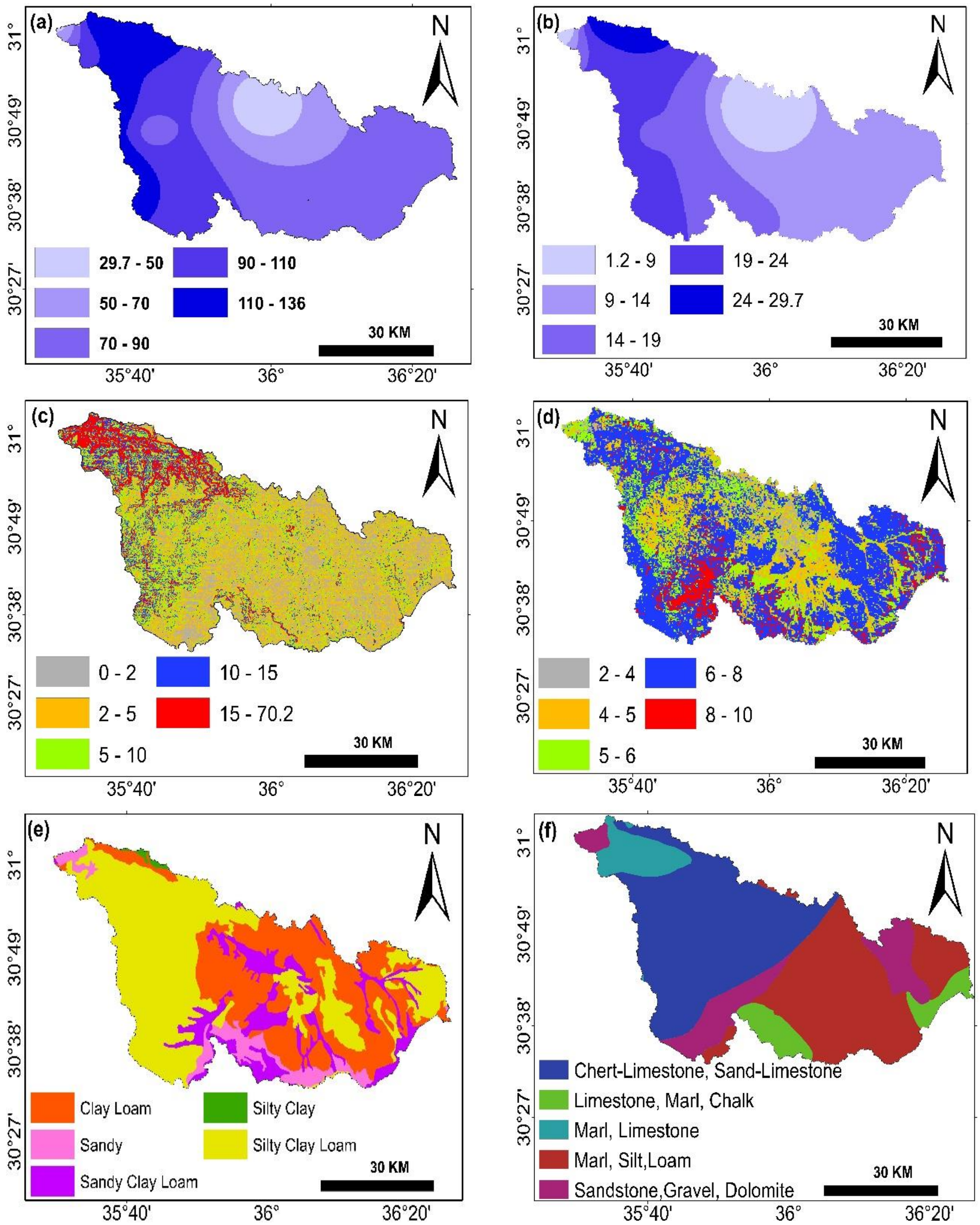

Figure 2: Classified RWH contributing factors maps: (a) rainfall intensity (mm), (b) runoff (mm), (c) slope (Degree), (d) flood susceptibility weight, (e) soil texture, (f) geology

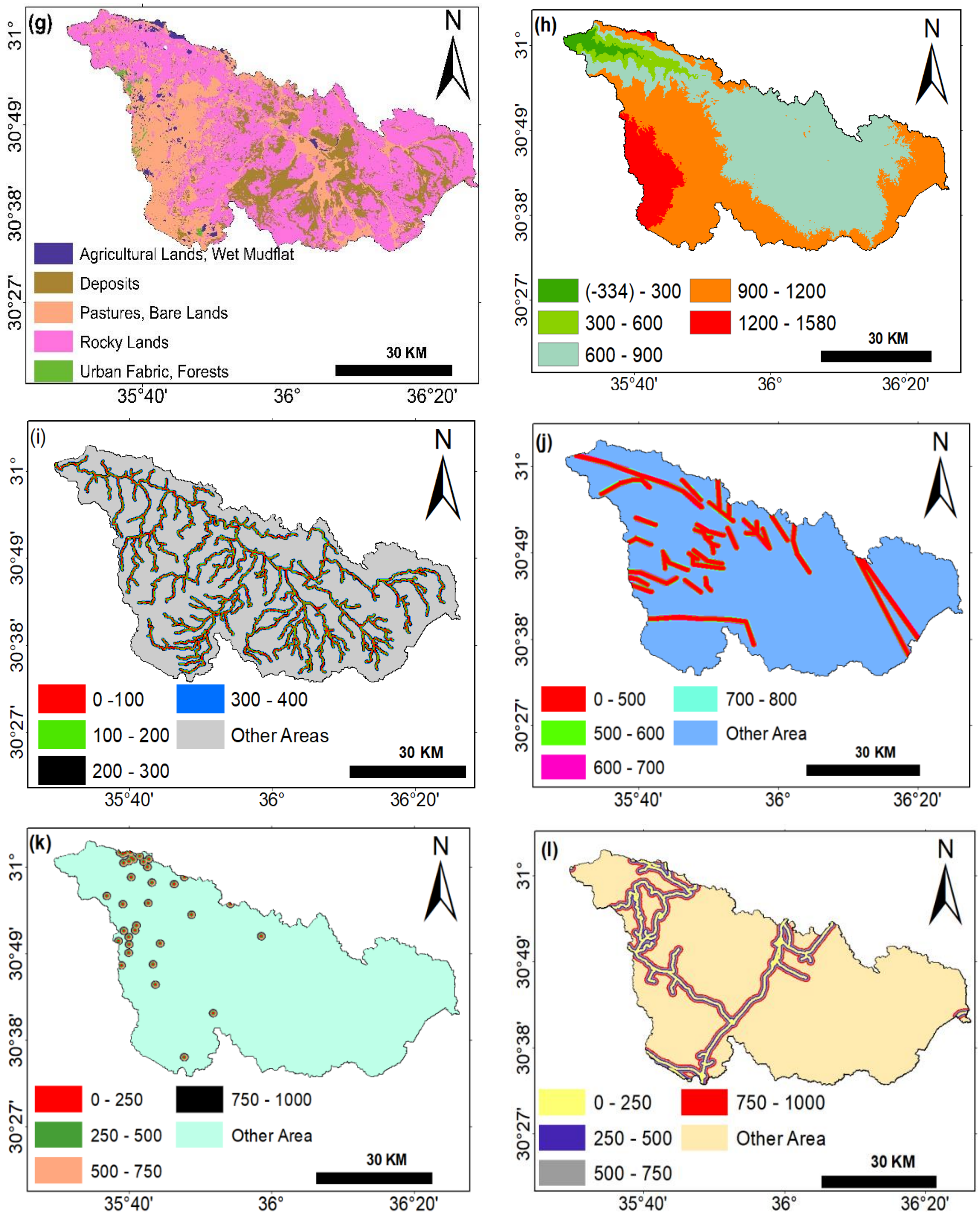

Figure 2: Classified RWH contributing factors maps: (g) LULC, (h) elevation, (I) rivers, (j) faults, (k) settlement centers, (l) roads

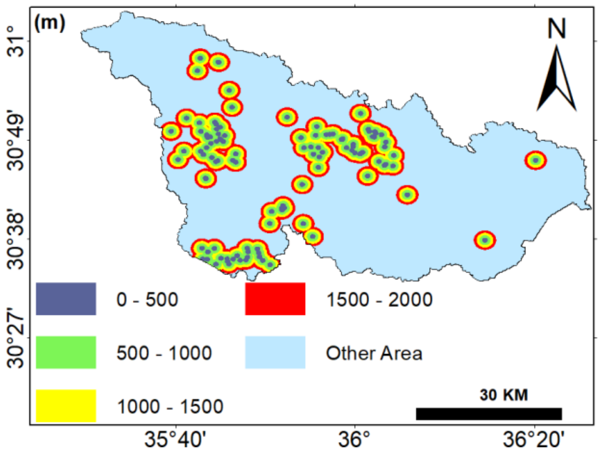

Figure 2: Classified RWH contributing factors maps: (m) wells

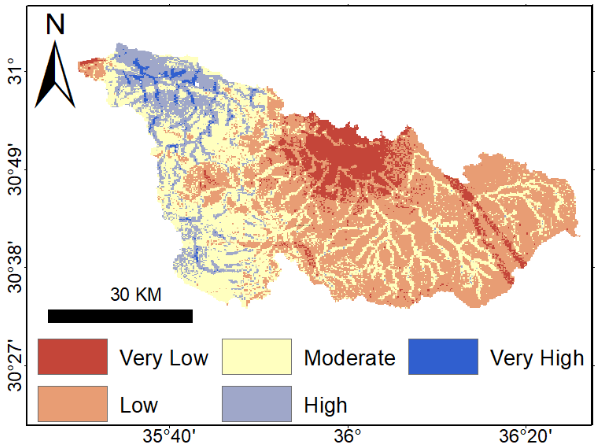

Figure 3: Final RWH suitable map for the study area

Table 5: Distribution of Suitable levels for RWH

Suitable level	Area (km^2)	percentage (%)
Very High	30.90	1.17
High	293.22	11.14
Moderate	840.09	31.91
Low	1213.46	46.09
very Low	254.93	9.68
Sum	2632.6	100

The use of GIS is considered one of the effective tools in determining RWH sites as a multidimensional natural hazard as it has a spatial dimension [44]. This is in addition to its importance in supporting the spatial decision through building multi-criteria models to determine the areas of RWH [45]. A final map of RWH was created for the study area to show the spatial distribution of RWH sites. Developing RWHs maps are also important to notify decision-makers and planners responsible for the management and evaluation, of available and sustainable water resources in a country like Jordan suffering from severe water scarcity (**Figure 3**). Areas with high and very high suitability are about 11.14% and 1.17%, respectively, while those with low and very low suitability represent, respectively, about 46.09% and 9.68 % of the total area of the study area (**Table 5**).

4. Conclusions

The application of AHP, integrated into GIS, is one of the most important methods for creating suitable RWH maps. In fact, assessing and analyzing RWH sites in different regions of the world is essential, especially where RWHs have economic, social, and environmental effects. Rainfall intensity, runoff, slope, flood susceptibility, soil texture, geology, LULC, elevation, rivers, faults, settlement centers, roads, and wells were major factors behind the control of the RWHs in the study area. The development of suitable RWH sites is designed to increase the availability of water resources in Jordan. Despite the low of areas with high and very high suitable levels for RWH, were about 12.31%, and areas with suitable moderate 31.91% of the total area, it is still significant in a country suffering of water scarcity. Therefore, the study recommends expanding RWH projects; this requires the effective management of water resources within the developed sites and the expansion of water harvesting projects in areas of high and very high suitable levels of RWH. Finally, the methodology used in this study can be considered a useful tool to study and propose potential RWH sites, and thus avoid flood risks.

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