

## Rainwater Harvesting as a Sustainable Solution for Managing Water Resources in the Soran Region -Case Study

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**Abstract:** Iraqi Kurdistan is experiencing water scarcity attributable to urbanization, population growth, and climate change, similar to worldwide challenges in dry and semi-arid areas. To address these pressures, there is a need for sustainable water management strategies that can sustain long-term development objectives. Rainwater harvesting (RWH) has become a relatively feasible and sustainable way to supplement water resources, but its successful application requires accurate site selection based not only on biophysical but also socio-economic factors. The study aims to identify the best locations of RWH systems in the Soran region based on Geographic Information System (GIS), Remote Sensing (RS), and Multi-Criteria Decision Analysis (MCDA). To do so, twelve parameters were included, which are biophysical elements (rainfall, runoff depth, slope, elevation, soil type, land use/land cover (LULC), distance to streams, drainage density, and lineament density) and socio-economic ones (distance to roads, villages, and rivers). Two methods, the Analytical Hierarchy Process (AHP) and the Weighted Sum Method (WSM), were applied and evaluated via MCDA. The use of R-square ( $R^2$ ), root mean square error (RMSE), and standard deviation (SD) as performance metrics showed that WSM yielded more reliable results, with values of 0.8069, 0.0545, and 10.48, respectively. The suitability map generated by WSM categorized the study area into five levels of RWH suitability: highly suitable (32.89%), suitable (31.58%), very highly suitable (16.97%), low suitability (11.32%), and unsuitable (7.17%). The analysis established three prior locations for dam construction. The study found three construction sites for a dam (Nawroin Dam, Shekhan Dam, and Leraban Dam). Overall, the research offers a robust spatial decision-support system that can be used to plan sustainable water resources and increase climate resilience in arid and semi-arid areas.

**Keywords:** Rainwater Harvesting; AHP; WSM; MCDA; GIS; RS; Dam

### 1. Introduction

Urban water supply systems face significant challenges in many cities across the world, alongside adaptations to the environment, economics, and climate [1, 2]. Moreover, in the last few decades. The demand for water for urban areas has experienced a substantial increase due to rapid urbanization and population growth [3]. Implementing RWH systems provides a practical solution. To guarantee a sufficient water supply for the cities and to promote sustainable development in its economy, environment, and society [4, 5].

Climate change impacts surface water availability and groundwater recharge. Future strategies for managing water resources must consider these implications when developing sustainable solutions. Decreased precipitation leads to desertification in humid regions, whereas increased rainfall in arid areas replenishes groundwater. [6, 7]. Arid and semi-arid countries rely on desalination or groundwater to exceed acceptable water-use limits. RWH facilitates aquifer recharge in the rainy

season through the collection of rainwater in ditches, ponds, or terraces. Climate change is altering precipitation patterns, potentially impacting groundwater recharge in arid and semi-arid regions, where recharge typically occurs after flooding events. Recharge events in arid and semi-arid regions generally occur after flooding [8].

Rainwater collection and storage in urban areas creates create opportunities to recycle it and use it as a substitute water supply for city uses. RWH is currently a popular method for conserving water and improving groundwater quality, helping to reduce the impact of drought. Cities globally are experiencing water scarcity; therefore, harvested rainwater can serve as a valuable supplementary water supply in these regions. Urban planners and the global scientific community are paying close attention to RWH as a substitute supply for integrated water resources management initiatives. RWH systems must enhance water availability and operate effectively in diverse biophysical and socioeconomic contexts. Many people escape poverty with RWH assistance. Sustainable living requires preserving the Earth and its resources. RWH systems can support future life by diverting, storing, and using natural water for home use [9, 10].

There are important cases of RWH plans in South Korea. In Portugal, the design of an RWH system concentrated on low-demand applications where water availability significantly exceeds water demand. The sponge city concept represents a novel approach to urban water management integration in China [11, 12].

Iraq currently faces a significant water shortage, and projections indicate that the situation may worsen further. Water collection methods will effectively mitigate the effects of this issue. This framework identified optimal locations for water storage systems by applying advanced technologies and established standards. Iraq could enhance its water resource management by monitoring the volume of rainwater that flows from land into various water bodies [13, 14].

Like other cities in the Kurdistan region, Soran experiences water shortages in the summer. Population development and urbanization make water provision difficult in the metropolis. Sorani city will rapidly grow housing and service projects after switching from a mayor to an autonomous administration. People will desire more water, especially since Soran relies mostly on surface water and a little on groundwater. The alternative to less groundwater and surface water use is RWH. The city's sustainable RWH option may reduce groundwater and municipal water stress. You can improve urban water supplies by harvesting and storing rainwater during dry seasons [13, 15].

Integrating GIS, RS, and MCDA will enhance model's effectiveness. This will lead to improved management of RWH facilities and the selection of suitable dam locations within the Soran region. The application of AHP and WSM approaches will be essential for determining and selecting optimal dam construction locations, thereby enhancing and ensuring more sustainable water systems for the Kurdistan Region. The AHP approach has been used in most global and local studies. Previous research has not employed this comparative methodology, so it was decided to compare the AHP approach and the WSM approaches for the regional case. This region, like other parts of Iraq, has evidently endured drought. The area's suitability for rainwater harvesting, characterized by substantial precipitation throughout the rainy season and favorable topography, prompted the initiation of this project to store the water in the reservoir and enhance regional benefits. The objective of this study is to construct and combine multiple thematic layers from diverse data sources and methods to develop plans for determining the best location for RWH. The study applied two methods to determine which yields more accurate results and will also cover their application in domestic water supply and irrigation, identifying implementation priorities and suitable locations for dam construction using advanced GIS techniques and MCDA models.

## 2. Methodology

### 2.1 Study Area

The study area is located in Erbil Governorate, Kurdistan region, Iraq, and around 100 kilometers from the center of Erbil city (Figure 1). It is located between the Iraq-Iran border from east to north, with coordinates between  $36^{\circ} 43' 15''$  N latitude and  $44^{\circ} 31' 55''$  E longitude, and  $36^{\circ} 52' 54''$  N latitude and  $44^{\circ} 54' 36''$  E longitude. The Soran district is situated within a mountainous area surrounding it, including several major mountain ranges, such as the Hassan Bag, Handren, Korek, Bradost, and Zozk ranges. These mountains often receive snowfall throughout winter. The Soran district experiences hot, arid summers and cold, moist, humid winters, with a maximum and minimum temperature of (44, -3) °C respectively. The topography of the study area reveals considerable variation over short distances. Due to the mountainous terrain, the highest elevation is 3,590 meters, while the lowest is 630 meters. The period of significant precipitation extends from late September to June. The average annual precipitation is 700mm. The basin area of the Study is 845 km<sup>2</sup>.

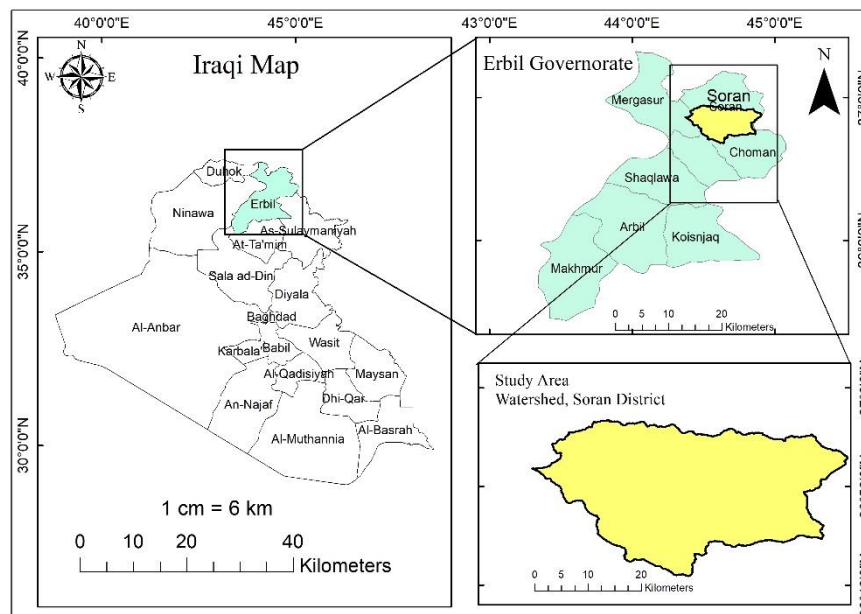


Figure 1: Location of Study Area

### 2.2 Parameters Employed for RWH Site Identification

The successful implementation of RWH involves several processes, including identifying appropriate criteria, evaluating the feasibility of classifying each criterion, and determining prospective locations.

**Biophysical factors:** The purpose of establishing biophysical criteria is to evaluate the watershed's natural characteristics that influence the availability of rainwater, surface runoff, and the overall environmental suitability for Rainwater Harvesting (RWH) deployment. This research employs the word "biophysical" to denote physical environmental elements [16, 17]. The study uses nine factors, such as Rainfall, Runoff, Slope, Elevation, Soil type, LULC, Distance to streams, Drainage Density, and Lineament Density.

**Socioeconomic factors:** ensure that rainwater harvesting systems are economically viable, socially acceptable, and consistent with the requirements and goals of local communities and the participants

involved [16, 18]. The study uses three factors: distance to roads, distance to villages, and distance to the river.

### 2.3 Data

To define the study area, a national border shapefile of Iraq was obtained from the DIVA-GIS database (<http://www.diva-gis.org/gData>). The shapefile provides the necessary geographic framework for spatial analysis, ensuring that all subsequent data is accurately positioned within the national context. The study region was delineated in ArcGIS 10.8.2 using standard geoprocessing tools after the file download.

The satellite images utilized in this research were obtained from the EarthDATA site (<https://search.asf.alaska.edu>). The raster layers have a spatial resolution of 12.5 meters, providing sufficient data for topographic, remote sensing, and land-surface analysis. Upon acquisition, the imagery was georeferenced to the World Geodetic System (WGS) 1984, UTM Zone 38N, ensuring spatial compatibility with other geospatial datasets intended for analysis.

The climate data utilized in this study were obtained from the Soran General Directorate of Agriculture, affiliated with the Ministry of Agriculture and Water Resources of the Kurdistan Regional Government, Iraq. The data pertains to monthly precipitation from 2001 to 2024, collected at four climatological stations within the study area. The continuity of these long-term observations was initially confirmed, and any gaps or discrepancies were addressed using standard climatological gap-filling techniques. The long-term average yearly rainfall for each station was estimated and spatially interpolated in ArcGIS using Inverse Distance Weighting (IDW) to create a continuous rainfall surface. This interpolated raster layer proved to be a significant input for assessing runoff potential and evaluating the viability of rainwater harvesting sites.

### 2.4 Watershed delineation from (DEM)

The terrain and hydrological analysis were conducted with a 12.5-meter DEM from ALOS PALSAR, obtained from the EarthDATA site (<https://search.asf.alaska.edu>). DEM was first incorporated into ArcGIS 10.8.2 using a geographic reference system verified and projected to WGS 1984, UTM Zone 38N, ensuring compatibility with other spatial datasets. Using the fill tool in (ARC Toolbox) to remove sinks that often form within DEMs and interrupt hydrological flow. After that, the process produces flow direction and flow accumulation information to guide water movement over the terrain. The process of identifying a stream network involves setting a threshold for flow accumulation data and snapping the outflow point to the stream system. Showing the drainage region as a raster, the procedure uses a flow direction raster alongside the snapped pour point., The raster data were converted to polygon format for better study and visualization needs.

### 2.5 Data Preparation and Modeling

Preparing the data required for both types of criteria. Biophysical parameters are (Rainfall, Runoff depth, LULC, slope, elevation, soil texture, stream order, drainage density, and lineament density). Socioeconomic parameters are distance to (roads, Villages, and river).

#### 2.5.1 Biophysical criteria

##### 2.5.1.1 Drainage Density

The ArcGIS Flow Accumulation output, which indicates stream order, can be employed alongside the DEM to accurately outline the stream network. Drainage lines can be generated by imposing a

threshold on a flow accumulation raster (**Error! Reference source not found.**). The subsequent phase in establishing a continuous stream network involves using the Con or Set Null tools to isolate cells with accumulation values exceeding the specified threshold. The threshold sets the minimum area that a cell must contribute to be considered part of a stream. The threshold value was chosen based on a mix of hydrological reasoning, watershed characteristics, and visual calibration.

Con allocates values to cells that satisfy the designated flow criteria based on a threshold, whereas Set Null removes those that do not. This method is employed to define high-flow areas and create a precise stream network for hydrological and RWH research.

The Drainage Density measures the amount of water flowing through a drainage basin of its overall area, as in Equation (1).

$$(1) \quad D_d = \frac{\sum L}{A_{basin}}$$

Where  $D_d$ =Drainage density,  $L$ = length of the stream (km), and  $A$ = area of the drainage basin ( $\text{km}^2$ )

The spatial resolution of 12.5 by 12.5 meters has been employed to delineate the drainage pattern network in the study area, which encompassed a basin area of  $845 \text{ km}^2$  and a total stream length of 2,542 km. The stream network has been extracted from the DEM's Flow Direction and Flow Accumulation outputs to calculate drainage density in ArcGIS. The next stream raster was transformed into polylines, and the Line Density tool calculated stream length per unit area. The drainage density raster was cropped to the watershed boundary for the study (**Error! Reference source not found.**).

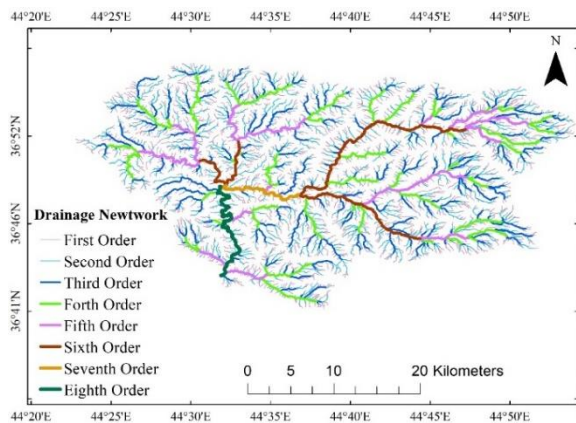


Figure 2: Map of stream order

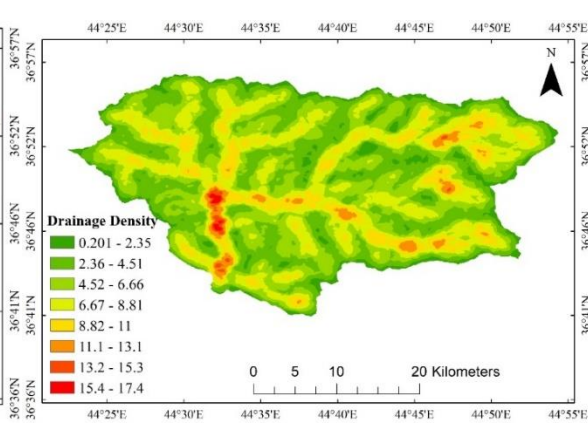


Figure 3: Map of Drainage Density

### 2.5.1.2 Rainfall data and distribution of rain gauges

Rainfall significantly influences RWH; thus, to create the rainfall map of the study area, data from the Soran, Rawanduz, Sidakan, and Mergasor stations have been employed (**Error! Reference source not found.**). The average annual rainfall was 667 mm, 721 mm, 815 mm, and 1397 mm at the Soran, Rawanduz, Sidakan, and Mergasor stations, respectively.

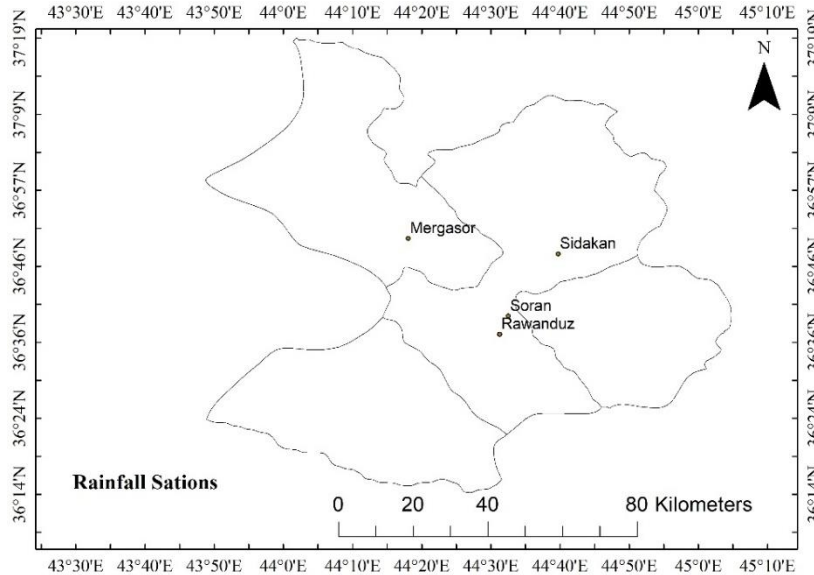


Figure 4: Distribution of meteorological stations within the study area

Uncertainty analysis in rainfall data is essential for evaluating the reliability of hydrological models. Measurements are generally affected by instrument constraints, geographical variability errors, and temporal variability errors, resulting in bias. The linear regression of this dataset, utilizing station identifiers, yielded an R-square value of 0.845 (Figure 5), indicating that 84.5 percent of the variance in rainfall was accounted for, while 15.5 percent remained unexplained. The match may be satisfactory; however, station identifiers may not serve as reliable predictors of precipitation. This limitation underscores the need for additional variables, such as elevation, geography, or climatic characteristics, to reduce uncertainty and improve forecast accuracy.

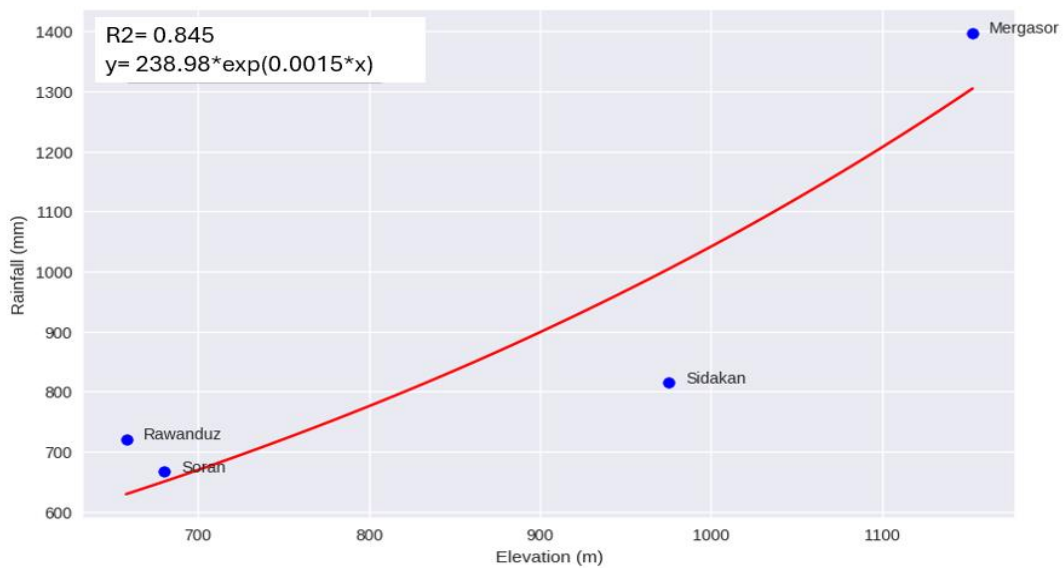


Figure 5: Uncertainty Analysis of Rainfall Data

The IDW method uses distance weighting to interpolate geographic data. It can be employed to predict future spatial rainfall data by examining current data from neighboring locations [19, 20]. Using Equation (2) to calculate IDW.

$$(2) \quad R_p = \sum_{j=1}^N w_j R_j$$

Where:

$R_p$  = Interpolated depth of rainfall (mm),  $R_j$  = Rainfall depths recorded at the surrounding stations (mm)

$N$  = Number of rainfall stations,  $w_j$  = the weight of each rainfall station

$D_j$  = the distance between each rainfall station and the unidentified site,  $x$  = the power

The annual rainfall data for the study area were initially imported into an Excel file and subsequently uploaded to ArcMap 10.8.2 to generate the rainfall map. The spatial analyst tools used IDW interpolation to map rainfall data across the entire region (Figure 6).

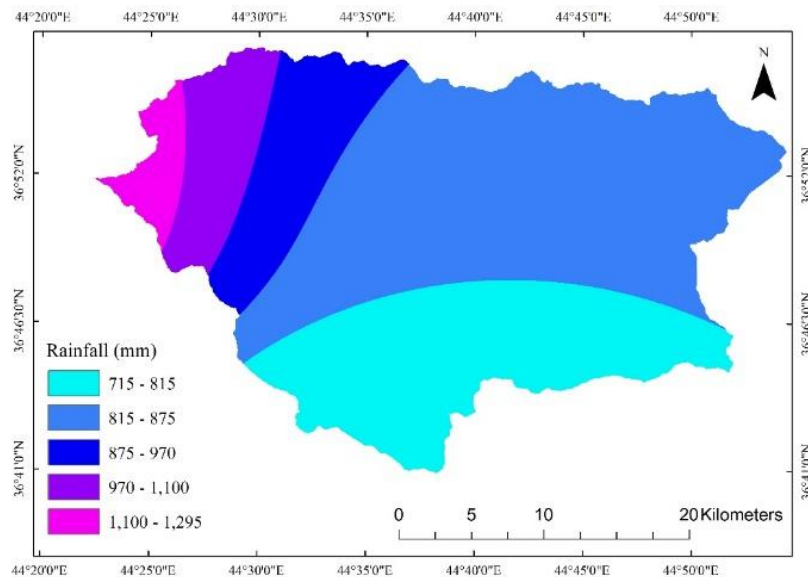


Figure 6: Spatial Distribution of Rainfall

### 2.5.1.3 LULC Map

The LULC data was sourced from Landsat 8 satellite imagery supplied by the National Aeronautics and Space Administration (NASA). The image was acquired on December 31, 2024, comprising 11 bands with a spatial resolution of 30 meters. The coordinate system utilized was the Universal Transverse Mercator (UTM) projection, namely Zone 38 North, founded on the WGS 84 datum. The LULC map was produced through supervised classification, delineating the area into nine separate categories, which include water, forest, grass, flooded vegetation, agriculture, shrub-scrub, built-up areas, bare land, and snow. Figure 7 (A).

### 2.5.1.4 Soil Texture Map

The soil parameter is among the most significant to consider when planning RWH. The way the Earth feels affects how well it absorbs water. Clayey soils, characterized by poor drainage, generate increased runoff, whereas sandy soils yield decreased runoff [21, 22]. The soil's textural class is based on how much clay, sand, and silt it has. The people frequently select regions with medium- and fine-grained soil for RWH, as clay material impedes water permeability and retains moisture effectively [22, 23]. To determine the soil texture of the study area, the researcher collected 11 soil samples from the book "A Reconnaissance Soil Survey of Erbil Governorate." These samples were all from my study area.

Table 1 presents soil texture analysis for different locations [24]. The findings are incorporated into the triangle of a texture analysis. Figure 7 (B) to ascertain soil classification. According to the soil triangle, we have seven types of soil. Using the Thiessen polygon in the analysis toolbox in Figure 7 (C) show the spatial distribution of soil types.

Table 1: Illustrates the Sample of Soils in the study area

ID	Location	Eastin (X)	Northing (Y)	Clay %	Silt %	Sand %
1	Kazhak	464324.8468	4067712.168	17	7	76
2	Dere	476999.7521	4068566.083	21	47	32
3	Nekawa	460963.5682	4073653.978	27	23	50
4	Sidakan	468292.5307	4073222.014	15	9	76
5	Bni Rashkin	479129.93	4075381.719	27	37	36
6	Girkal	452234.5283	4078172.396	43	31	26
7	Darhol	466581.5534	4081400.953	16	8	76
8	Kolaka	451352.4411	4085128.641	40	28	32
9	Shushin	460301.8272	4085535.847	18	16	66
10	Mazne	456411.49	4067390.535	41	51	8
11	Dara	453292.21	4073015.257	39	51	10

To classify soils according to how well they control runoff after the same amount of precipitation, the United States' Natural Resources Conservation Service (NRCS) created the Hydrological Soil Group (HSG) [25]. The capability of the soil to absorb water, the depth of the water table, and the permeability of the soil are elements that affect HSGs A, B, C, and D [26]. From the soil data in the study area, there are different types of soil, and each soil corresponds to the HSG group according to Table 2,

Table 3 presents the soil type corresponding to the HSG group types, and **Error! Reference source not found.**

Table 2: HSG derived from soil properties (27)

Soil Texture	HSG
Sandy Loam	A
Loam, Sandy Clay Loam	B
Clay Loam, Silty Clay Loam	C
Clay, Silty Clay	D

Table 3: Soil type corresponding to HSG

Soil Group	Infiltration Rate	Runoff Potential	Soil texture (Type)
A	High	Low	Sand, loamy sand, or gravel sand
B	Moderate	Moderately Low	Silt loam or loam
C	Slow	Moderately High	Sandy clay loam or silty clay loam
D	Very Slow	High	clay loam, sandy clay, silty clay loam, silty clay, and clay

### 2.5.1.5 Soil Conservation Service - Curve Number (SCS-CN) Method

The SCS-CN approach is widely utilized to assess surface runoff, groundwater recharge, and streamflow, which infiltrate the soil and generate leachate from landfills during periods of precipitation. [28]. The SCS-CN model has been utilized to predict runoff depth in the study area, while RS has been used to create a LULC map. The soil map of the study area was digitized, and the rainfall data were interpolated utilizing ArcGIS 10.8.2. The SCS-CN results have been utilized to ascertain the runoff depth from precipitation for RWH designs. Also, the SCS model was created by equation **Error! Reference source not found.** [29].

$$(3) \quad Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Where:

$Q$  = Depth of runoff (mm),  $P$  = Rainfall (mm),  $S$  = Potential maximum retention (mm)

Potential maximum retention is computed by equation **Error! Reference source not found.**)

$$(4) \quad S = \frac{25400}{CN} - 254$$

CN is measured by looking at how soil and land cover affect the way rainwater flows. The CN might be anything from 1 to 100. Lower Curve Number values mean less runoff, whereas higher CN values mean more runoff.

The Antecedent Moisture Content (AMC) index can assess watershed moisture by aggregating rainfall over the five days preceding a storm. A high index value signifies elevated runoff. There are three primary categories of AMC. [30, 31].

1. AMC I used at dry conditions when the soils were dry.
2. AMC II used average conditions.
3. AMC III is used for wet conditions (heavy rainfall or saturated soil).

### 2.5.1.6 Evaluation of CN

The CN has been generated by combining the LULC and HSG layers into an index file created with the ArcGIS tool. Using a LULC map and soil maps categorized into HSGs and hydrologic

conditions, CN is approximated per pixel for the study region. Applying AMC I (dry condition) is the appropriate strategy for Iraq, given its classification as an arid region. The soil has negligible moisture before precipitation, thereby enhancing permeability and reducing the potential for water runoff. Correction factors should be utilized for CN computations when operating under AMC I conditions.

The CN values are derived from the standard NRCS tables, with the assumption that Iraq's arid climate is AMC I (dry condition). Table 4 and Figure 7 (E).

Table 4: Value of CN corresponding to LULC and HSG

LULC Type	HSG A	HSG B	HSG C	HSG D
Water	100	100	100	100
Forest	30	55	70	77
Grassland	39	61	74	80
Flooded Vegetation	50	66	77	83
Agriculture (Crops)	67	78	85	89
Shrub-Scrub	35	56	72	79
Built-up (Urban)	85	90	95	98
Bare Land	77	86	91	96
Snow/Ice	100	100	100	100

### 2.5.1.7 Evaluation and Generating Runoff Depth

To evaluate the runoff depth, the possible maximum retention (S) (equation (5)) was initially derived using the Curve Number (CN) map. In ArcGIS, each pixel's S-value was calculated using the standard SCS-CN equation in the Raster Calculator, yielding a spatially continuous raster layer of potential retention. The initial abstraction (Ia) was determined (0.2S), and then, an Ia raster layer was produced using map algebra. Finally, the runoff depth was calculated in the Raster Calculator, producing a runoff-depth raster that assigned runoff values to each pixel within the study area. This approach ensures that runoff depth is estimated routinely and spatially clearly for use in hydrological and RWH suitability analysis. Figure 7 (F)

$$(5) \quad S = \frac{25400}{CN} - 254$$

### 2.5.1.8 Slope

The gradient's slope can be assessed using the DEM. The Food and Agriculture Organization (FAO) defines five categories for slope assessment, with the most appropriate categories demonstrating reduced steepness relative to those with increased steepness (

Table 5) [32, 33]. The gradient of the slope is a critical determinant in the allocation and execution of RWH. Regions with significant elevation and ample precipitation are deemed appropriate for considerable runoff generation. The study area exhibits complex slopes, each oriented in diverse directions (Figure 7 (G)).

No.	Slope %	Slope class
1	< 2	Flat
2	2 - 8	Undulating
3	8 - 15	Rolling
4	15 -30	Hilly
5	>30	Mountainous

Table 5: Classification of slope

No.	Slope %	Slope class
1	< 2	Flat
2	2 - 8	Undulating
3	8 - 15	Rolling
4	15 -30	Hilly
5	>30	Mountainous

### 2.5.1.9 Elevation

This criterion, this characteristic, is essential for identifying prospective water collection sites. Elevation is closely associated with water harvesting, as higher altitudes are less advantageous due to the extensive earthworks required. The research area has a maximum elevation of 3590 m and a low elevation of 630 m. The altered digital elevation model subsequently categorizes the elevation into five classifications. Figure 7 (H). The classifications include low hills/valleys, lower mountains/mid-hills, mountains, alpine/high mountains, and extremely high mountains [34-37].

### 2.5.1.10 Lineament Density map

Lineament density is the aggregate of linear or curvilinear features, such as faults and fractures, within a specified area. Lineaments challenge the selection of sites for rainwater harvesting operations. Individuals prefer to avoid developing in regions with poor geology due to the presence of fissures and joints that facilitate the ascent of water to the surface. The spatial analysis utility employed the line density command in ArcGIS to generate the lineament density. The map of lineament density is categorized into five classes ( Figure 7 (I)).

## 2.5.2 Socioeconomic criteria

### 2.5.2.1 Distance to Roads

Roads provide a critical socio-economic function in the area by enabling accessibility to water for residential and animal purposes. Consequently, situating potential dam locations in proximity to roadways can be beneficial by minimizing transportation expenses. [16, 38, 39]. In the study area, the maximum distance separating pixels from roads is 12.39 kilometers. It is recommended at least 250 m as a minimum distance to maintained from roads to prevent potential conflicts between future road expansion and the proposed dams, as well as for safety reasons. [16, 40-42]. From the Spatial analysis tool using Euclidean distance, the buffer areas have been marked to the right and left of the road to facilitate passage. After that, the distance to roads is classified in five classes (250, 750, 1500, 2000, 2500), Figure 7 (J).

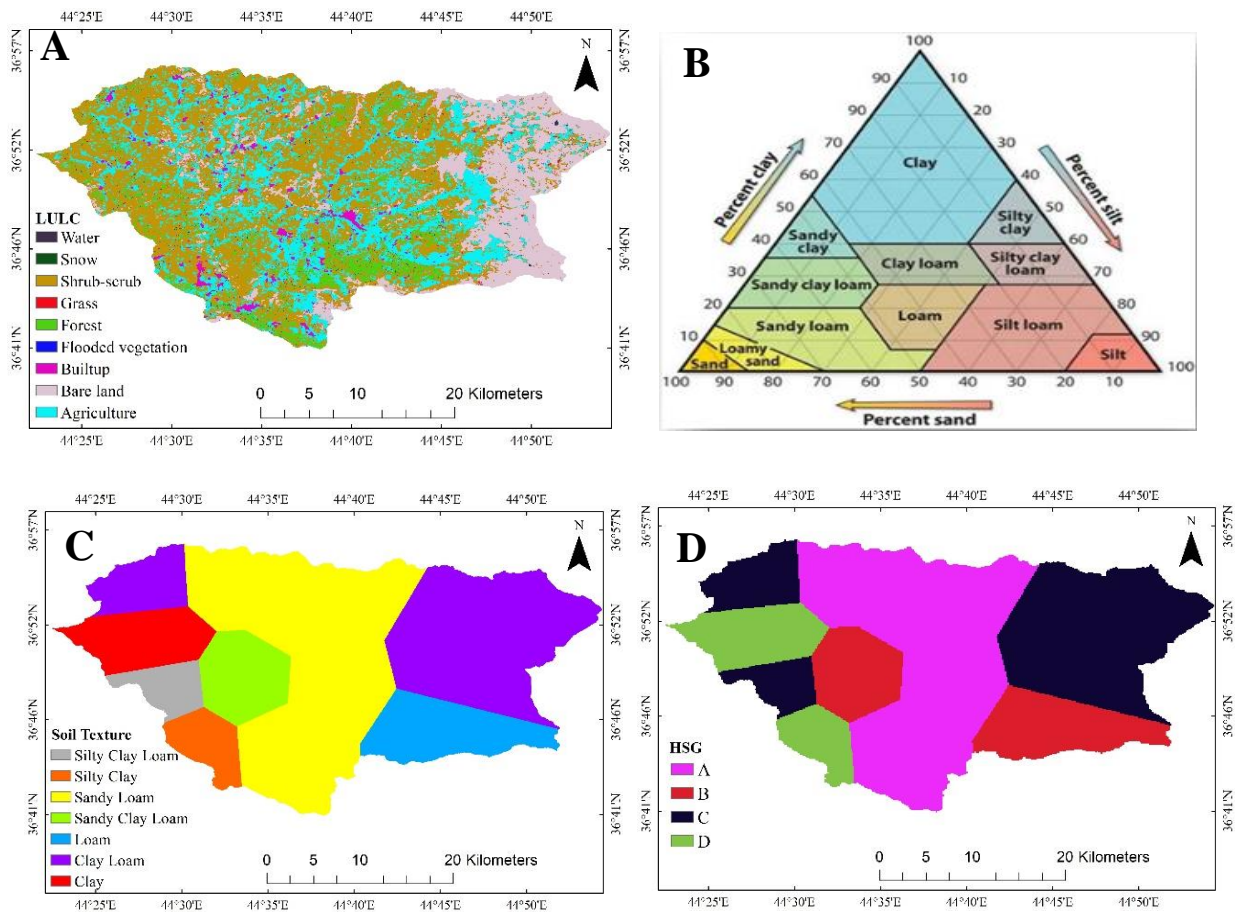
### 2.5.2.2 Distance to Villages

The study focuses on the local community, which is underscored by the distance to villages. Additionally, the distance between optimal RWH sites and residential areas is considered a critical factor. [16, 43]. Additionally, this considers the safety implications of determining the site of RWH that is located over 500 meters from residential areas. [44, 45]. From the spatial analysis tool in

ArcGIS, using the command of Euclidean distance to specify the distances from villages and classify them into five classes (500, 2000, 2500, 3000, and more than 3000), Figure 7 (K).

### 2.5.2.3 Distance to River

The analysis of distance to the river is essential, as shorter distances correspond with heightened soil permeability, leading to improved infiltration and reduced capacity for holding collected surface runoff in RWH systems. Another issue is that we depend on the rainfall resource, not the source of surface water to far away from the river, taking a distance from the rivers, from the spatial analysis tool in ArcGIS using the command of the Euclidean distance to determine distances from rivers and categorize them into five classes (500, 1000, 1500, 2000, and more than 2000) Figure 7 (L).



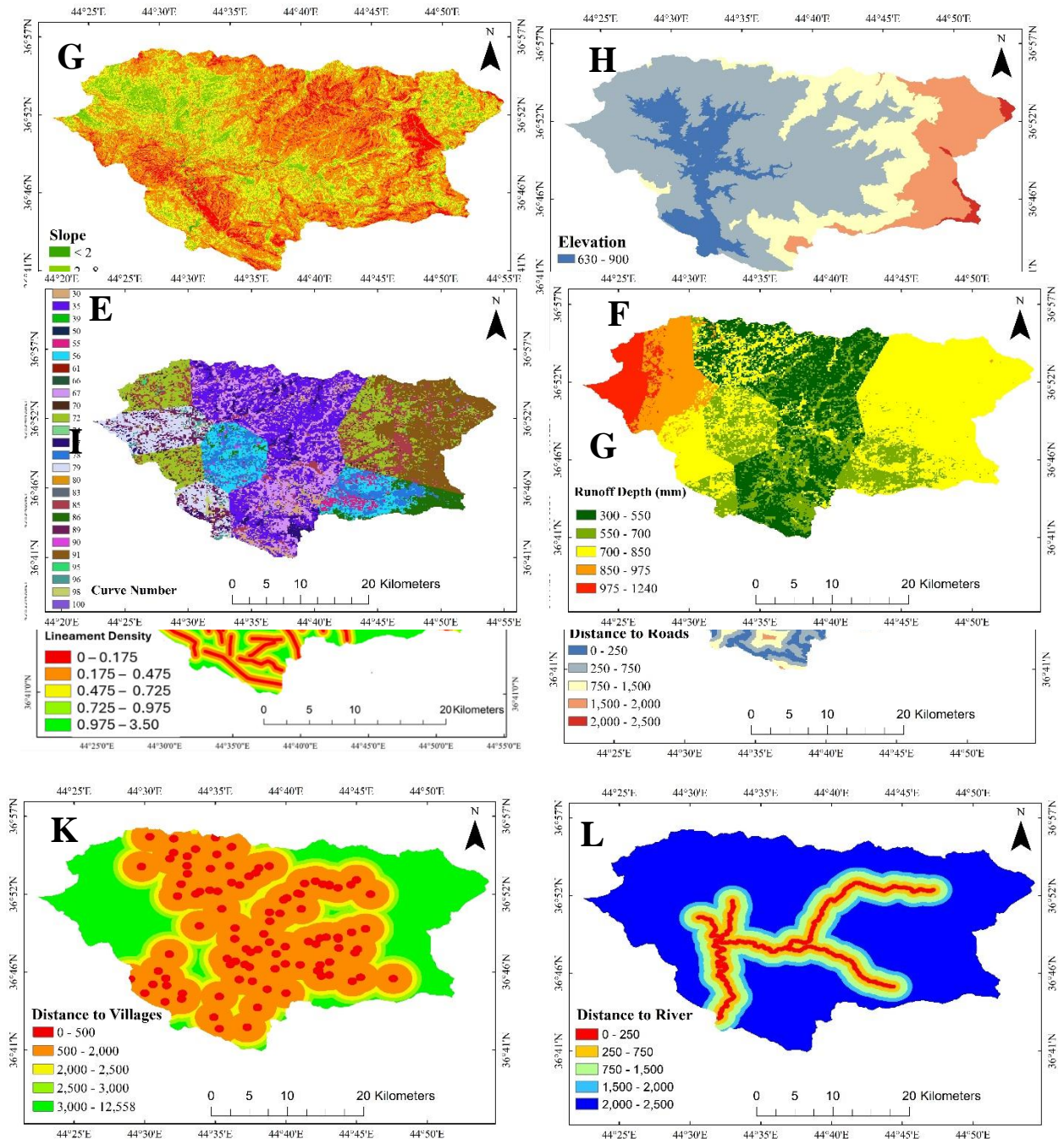


Figure 7: (A) LULC, (B) Soil Texture Triangle, (C) Soil Texture, (D) HSG, (E) Curve Number, (F) Runoff Depth, (G) Slope map, (H) Elevation Map, (I) Lineament Density Map, (J) Distance to Roads, (K) Distance to Villages, (L) Distance to River

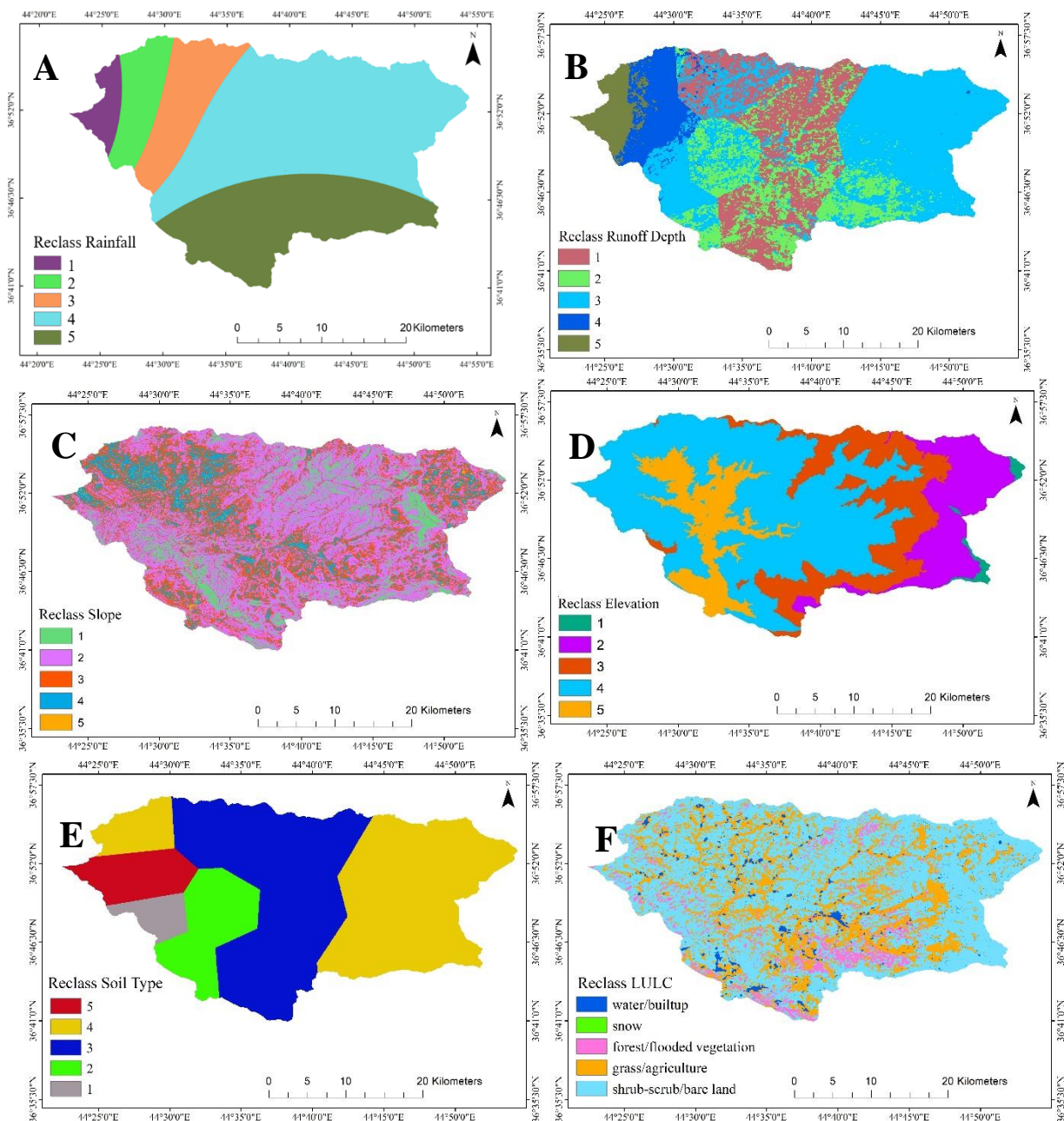
### 2.6 Classification of the Criteria

The suitability evaluation of rainwater harvesting systems accomplishes spatial analysis of numerous hydrogeological and environmental elements using GIS integrated with MCDA. [46]. The parameter

map was divided into five distinct classes based on the degree to which each category meets the requirements for RWH utilization. The classification level and its descriptions are presented in Table 6. Reclassification of thematic layers according to suitability classes from (1 – 5), distribution of the values of each layer by priority and importance by the Saaty Scale from Table 7, Figure 8 (A-L).

Table 6: Suitability classification of thematic layers

Suitability Class	Description
1	Unsuitable
2	Low suitable
3	Suitable
4	High suitable
5	Very highly suitable



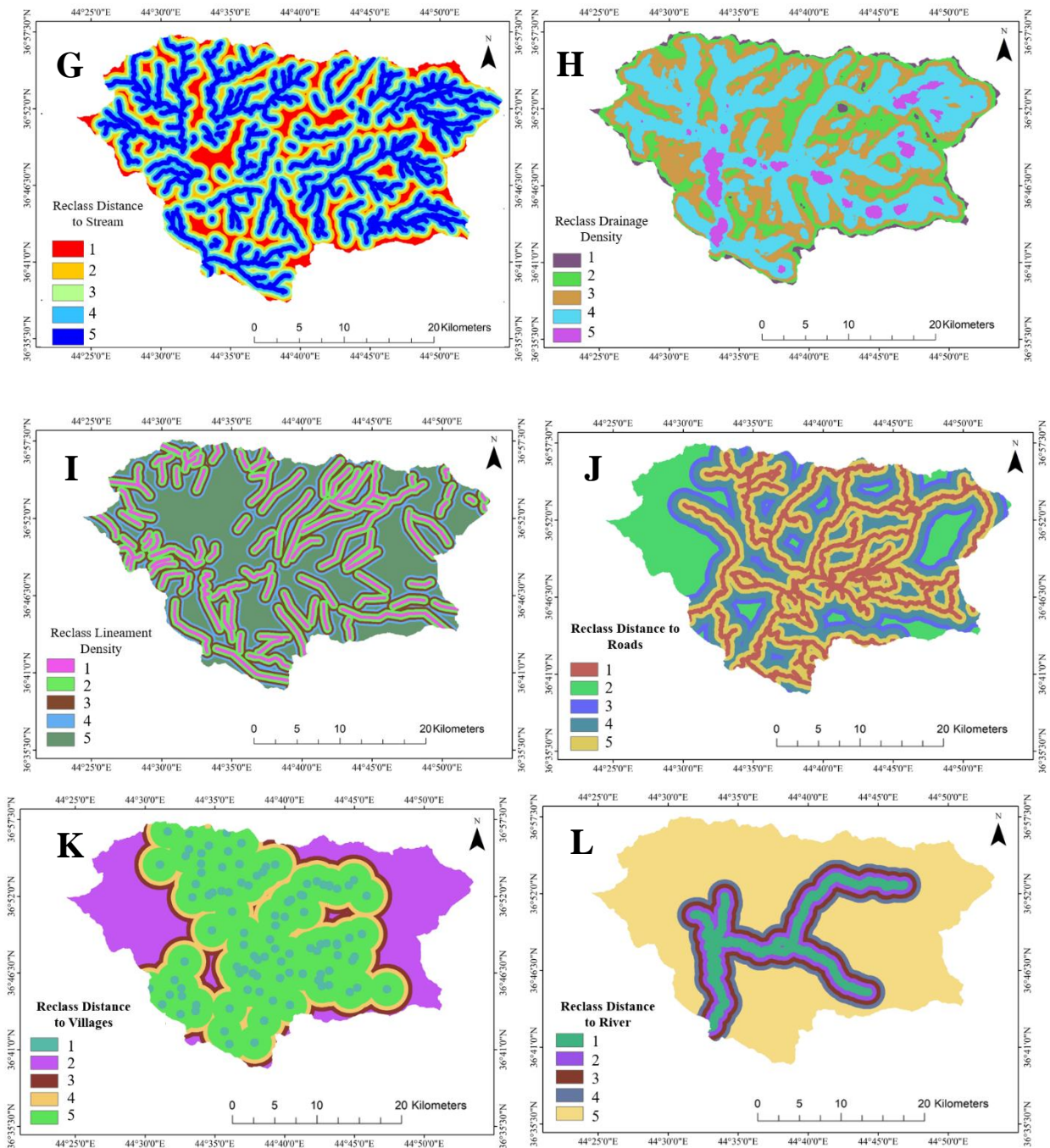


Figure 8: Reclassification of Input thematic layers; (A) Rainfall, (B) runoff depth, (C) slope, (D) elevation, (E) LULC, (F) soil type, (G) Distance to streams, (H) drainage density, (I) lineament density; (J) distance to roads, (K) distance to residential areas, (L) distance to river

### 2.7 Multi-criteria Decision Analysis

MCDA is a systematic approach intended to evaluate intricate issues characterized by conflicting criteria [47, 48]. Unlike single-criterion approaches, it integrates quantitative and qualitative factors using methods such as AHP, TOPSIS, and ELECTRE [49, 50]. MCDA is widely applied in environmental and water resource management, offering transparency in trade-off analysis [51, 52].

### 2.7.1 The Analytical Hierarchy Process (AHP)

Saaty introduced the Analytical Hierarchy Process (AHP) as a method for decision-making under conditions involving many criteria [53]. AHP is the most prevalent and effective method in MCDA to assess the relative significance of each parameter addressed in the study. AHP has been recognized as the most effective decision-making strategy for selecting acceptable RWH locations utilizing GIS software. The AHP has been extensively employed in many research investigations to identify appropriate RWH sites [54, 55]. The AHP facilitates those who make decisions to effectively utilize subjective information and expertise via pairwise comparisons to determine the appropriate weights of parameters [56, 57]. The method begins by identifying the spatial appropriateness of RWH. It then specifies the standards and carries out pairwise comparisons. At last, it specifies the choices and the degree of fit of the sites by means of repeated pairwise comparisons for every alternative under every criterion, consequently creating alternate weights. Finally, all parameters and alternate weights are combined to get the results for decision-making [57-59].

The pairwise comparison evaluates twelve criteria to ascertain whether a criterion holds greater significance for a specific purpose. Assigning a relative importance rating from 1 to 9 to each factor for construction purposes [23, 60-62], Table 7 elucidates the evaluation of 12 parameters on a continuous scale of points from 1 to 9.

Table 7: Pairwise comparison scale [53]

<b>Intensity of importance</b>	<b>Description</b>
1	Equal importance
3	The moderate importance of one over another
5	Very important or Essential
7	Most importance
9	Extreme importance
2,4,6,8	Intermediate values between the two adjacent decisions

The matrix of pairwise was generated for the twelve parameters utilized in the study. Each parameter was ordered based on its importance and effectiveness on the RWH. Rainfall, Runoff Depth, Slope, Elevation, LULC, Soil Type, Distance to streams (Stream Order), Drainage Density, Lineament Density, Distance to Roads, Distance to the villages, and Distance to Rivers (Figure 8). Earlier studies in the fields provided a framework to ascertain the importance of the criteria [42, 63-66].

Table 8: The AHP Matrix of Pair-wise Comparison

Factors	Rainfall	Runoff Depth	Slope	Elevation	Soil Type	LULC	Distance Streams	Drainage Density	Lineament Density	Distance to Roads	Distance to Villages	Distance to River
Rainfall	1	1	2	3	4	4	5	5	6	7	7	9
Runoff Depth	1	1	2	2	3	4	5	5	6	7	7	8
Slope	1/2	1	1	1	3	3	4	4	5	6	7	8
Elevation	1/3	1/2	1	1	2	3	4	4	5	6	6	7
Soil Type	1/4	1/3	1/3	1/2	1	2	3	3	4	5	5	6
LULC	1/4	1/4	1/3	1/3	1/2	1	2	2	3	4	4	5
Distance Streams	1/5	1/5	1/4	1/4	1/3	1/2	1	1	3	4	4	5
Drainage Density	1/5	1/4	1/4	1/4	1/3	1/2	1	1	2	3	3	5
Lineament Density	1/6	1/6	1/5	1/5	1/4	1/3	1/3	1/2	1	3	3	4
Distance to Roads	1/7	1/7	1/6	1/6	1/5	1/4	1/4	1/3	1/3	1	2	3
Distance to Villages	1/7	1/7	1/7	1/6	1/5	1/4	1/4	1/3	1/3	1/2	1	2
Distance to River	1/9	1/8	1/8	1/7	1/6	1/5	1/5	1/5	1/4	1/3	1/2	1
Sum	4.297	4.611	7.801	9.010	14.983	19.033	26.033	26.367	35.917	46.833	49.500	63.000

2.7.2 Evaluation of Consistency comparison of pairwise

The evaluation provides the validity of the estimated weights by utilizing a numerical index called the Consistency Ratio (CR). The CR computation determines the degree of pairwise comparison accuracy. CR Criterion relative weight estimation relies on the consistency ratio computation. Establishing their ratio produces the CR from both the Consistency Index (CI) and Random Index (RI). A CR below 10% indicates a satisfactory assessment of paired items. adequate. A CR value exceeding ten requires another assessment of the criterion pairs [23, 67, 68]. Equation **Error! Reference source not found.**) is used to calculate the CR value.

$$(6) \quad CR = \frac{CI}{RI}$$

The number of criteria is 12. The RI can be calculated using Saaty's table, depending on the matrix order. This study used twelve criteria, yielding a random index value of 1.54. Table 9 shows the random index values as a function of the number of parameters.

Table 9: Random Index for the number of parameters [23, 66].

Number of parameters	3	4	5	6	7	8	9	10	11	12	13	14	15
Random Index (RI)	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49	1.51	1.54	1.56	1.57	1.58

The CI can be found from the following procedures:

The first parameter's weight (Rainfall = 0.2082) is multiplied by the sum of the first column (Rainfall) of the initial pairwise comparison matrix. Subsequently, calculate the sum of the second column of the initial pairwise comparison matrix and multiply it by the weight of the second parameter (runoff depth).

For every weight criterion, repeat these steps. Lastly, the consistency vector ( $\lambda_{max}=12.7772$ ) is used to compute the CI in accordance with Equation **Error! Reference source not found.**)

$$(7) \quad CI = \frac{\lambda_{max}-n}{n-1}$$

Where:

$\lambda_{\max}$  = The highest eigenvalue of the pairwise comparison matrix, n Number of parameters (size of the matrix)

The consistency index is 0.0459, which is equal to 4.59% also it is also less than 10% in the range of acceptance. This means that the 4.59% CI shows good results for factor comparison.

### 2.7.3 Weighted Overlay Analysis

Data preparation for all thematic layers, which includes georeferencing, resampling, and normalization to a standard scale to ensure accuracy and fit. Afterward, each part of the data was given a weight according to its importance in identifying the most appropriate RWH site, which was determined through a literature review. [69-71]. Using equation **Error! Reference source not found.**) to analyze the weighted overlay.

$$(8) \quad w = \sum_{i=0}^n x_i * w_i$$

Where  $w$  is the weighted overlay,  $n$  is the number of decision parameters,  $x$  is the normalized parameter, and  $w_i$  is the weight of each parameter. The cell and pixel values of the raster layers are multiplied by their weights or percentage influences from the AHP analysis. The RWH output raster map is then created by combining the results.

### 2.7.4 Weighted sum method (WSM)

The WSM is the most utilized and easiest MCDA technique for weighing several options in the context of different choice parameters [72, 73]. A major drawback of using weighted sums exists in the equal weighting of factors between all criteria [16, 74, 75]. The classification order of thematic layers was established by the expert and prior literature using their professional expertise. Five categories were assigned to each factor in

Table 10. To find the value of WSM, use Equation **Error! Reference source not found.**)

(9)

Factors	Criteria Weights	Criteria weight (%)
Rainfall	0.2082	<b>21</b>
Runoff Depth	0.1921	<b>19</b>
Slope	0.1386	<b>14</b>
Elevation	0.1268	<b>13</b>
Soil Type	0.0870	<b>9</b>
LULC	0.0633	<b>6</b>
Distance Streams	0.0503	<b>5</b>
Drainage Density	0.0454	<b>5</b>
Lineament Density	0.0337	<b>3</b>
Distance to Roads	0.0226	<b>2</b>
Distance to Villages	0.0185	<b>2</b>
Distance to River	0.0135	<b>1</b>

$$WSM = \sum_{j=1}^n w_j * x_{ij}$$

Where  $n$  is the number of parameters,  $x_{ij}$  is the real value of  $j$  parameter, and  $w_j$  is the weight of the  $j$  parameter

### 2.7.5 Sensitivity Analysis

In examining the MCDA-AHP model's ability to identify the best locations for RWH, the study performed a sensitivity analysis on the model's optimal placements and the various criteria weights. The weights derived from AHP were adjusted in a step-wise fashion to either the positive or negative side of the continuum by 10, 20, and 30%, respectively, while the other weights were adjusted accordingly to remain neutral. The adjusted weights simulated a predetermined scenario that corresponded to recalibrating the suitability map in a step-wise fashion using the previous methodology. The simulation maps were aligned with the baseline to assess the stability of the MCDA AHP model. Based on this, we were able to observe the extent to which the assigned weights shifted the configuration of optimal placements for RWH.

## 2.8 Dam Site Selection

Identifying a site for a dam is not a new approach to mitigating water shortages, and the usual ways to address them are expensive and time-consuming. Nowadays, new technologies let us use the most resources at the best price [76]. GIS and MCDA approaches, such as AHP and WSM, can be integrated to establish a comprehensive framework for site selection of a dam. This approach facilitates the analysis of environmental, geological, hydrological, and socio-economic dimensions, ensuring coherence in decision-making. This method discovers ideal sites that reconcile technical viability, environmental sustainability, and socio-economic factors.

## 3. Result and Discussion

### 3.1 Stream order

According to the output there are 8 streams in the study area (Figure 2), using ArcGIS hydrology tool to find the length of stream after converting the stream order to stream feature, the total length of all streams is 2,542 km, the first order is 1289 km (about 0.5% of total length of drainage length), The second and third order streams have significant drainage lengths., 634 km (25%) and 309 km (12%) respectively. The fourth is 155 km (6%), the fifth is 79 km (3%), the sixth is 49 km (2%), and the seventh stream is 9.9 km (0.4%), which has the shortest stream length. Mainly, the Balakyan River is the final stream, having a Length of 17.6 (0.7%).

### 3.2 Analytical Hierarchy Process

The researchers simplified the complexity of their difficulties using the AHP technique. The AHP enhances decision-making by providing established hierarchical criteria for selecting alternatives—a sequence of pairwise evaluations in both subjective and objective contexts. Diverse factors were assessed to comprehend the decisions. Weights and rankings were appropriately assigned to each parameter. We found that rainfall had the highest weight with 21%, followed by runoff with 19% and distance to the river with 1%, which has the minimum value. The outcome of the pairwise comparison matrix utilized to ascertain the weights of the components is shown in

Table 10. Normalized Pairwise comparison: Divide every component by the sum of its column from the matrix comparison the matrix. The weight equal to 1 of pairwise to obtain normalized sum of each must be or 100%.

Factors	Criteria Weights	Criteria weight (%)
Rainfall	0.2082	<b>21</b>
Runoff Depth	0.1921	<b>19</b>
Slope	0.1386	<b>14</b>
Elevation	0.1268	<b>13</b>
Soil Type	0.0870	<b>9</b>
LULC	0.0633	<b>6</b>
Distance Streams	0.0503	<b>5</b>
Drainage Density	0.0454	<b>5</b>
Lineament Density	0.0337	<b>3</b>
Distance to Roads	0.0226	<b>2</b>
Distance to Villages	0.0185	<b>2</b>
Distance to River	0.0135	<b>1</b>
LULC	0.0633	<b>6</b>
Distance Streams	0.0503	<b>5</b>
Drainage Density	0.0454	<b>5</b>
Lineament Density	0.0337	<b>3</b>
Distance to Roads	0.0226	<b>2</b>
Distance to Villages	0.0185	<b>2</b>
Distance to River	0.0135	<b>1</b>

Table 10: AHP Final Assigned Weights

### 3.3 Sensitivity analysis to MCDA

The sensitivity analysis demonstrates that the AHP weights affect the model's stability in varying degrees. The model maintained stability in the AHP weights and baseline for RWH, and in the optimal placements, even when the weights were adjusted by only 10 to 20%. Any movements in high and low RWH suitability placements in the baseline scenario for the MCDA AHP model occurred, but only to a minimal degree. The AHP weight was set to 30%, and the model baseline was adjusted accordingly. Improvements and high-activity and low-activity zones were unchanged in position relative to the baseline. A substantial portion of the MCDA-AHP model was weighted, and the zones of suitability for RWH were revised.

### 3.4 RWH Suitable Zone for AHP

The RWH-suitable zone map is classified into five suitability categories. 'Very High suitable,' 'High suitable,' 'Suitable,' 'Low suitable,' and 'Unsuitable.' The outcomes reveal that the 'High Suitable' suitability class prevails, covering 446.6572 km<sup>2</sup> (55.22%) of the study area. This class is extensively spread, with a notable presence in both the northern and southern parts. The "Suitable" suitability class, which is the second largest, covers 303.79 km<sup>2</sup> (35.95%) and is mostly found in the center region from east to west. The third suitability class is 'low suitable,' covering 62.43125 km<sup>2</sup> (7.38%); it's distributed abundantly in the western area and to a lesser extent in the other areas. The fourth suitability class, 'Unsuitable,' covers 7.53 km<sup>2</sup> (0.89%), which is distributed in the western part of the study area. The final suitability class is 'Very highly suitable,' which covers 0.0123 km<sup>2</sup>; we can neglect it due to the very low value presented in Table 11 and **Error! Reference source not found..**

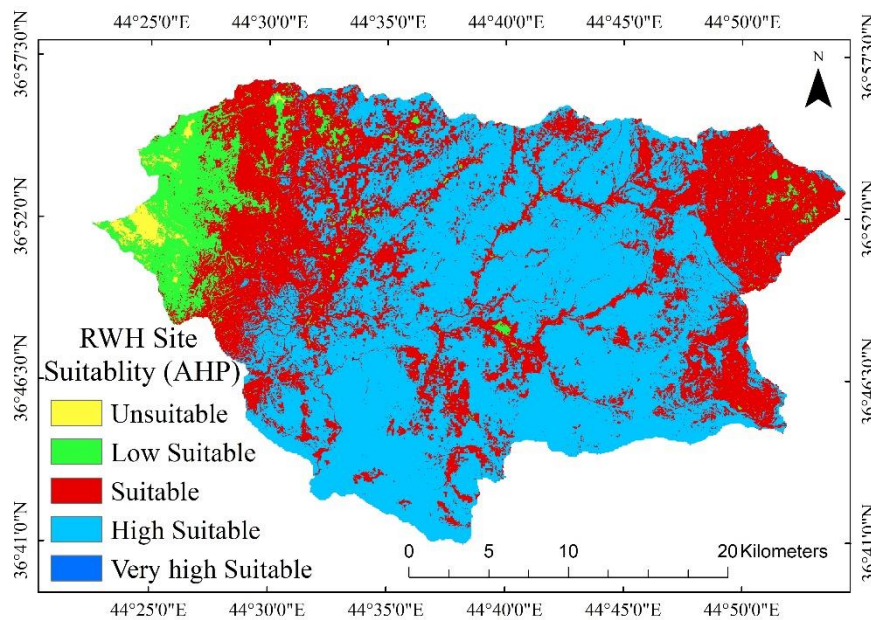


Figure 9: Final Suitability result of AHP

### 3.5 RWH Suitable Zone for WSM

The RWH-suitable zone map is categorized into five suitability classes: 'Very High suitable,' 'High suitable,' 'Suitable,' 'Low suitable,' and 'Unsuitable.' The outcomes of WSM revealed that the 'High Suitable' suitability class prevails, covering 276.95 km<sup>2</sup> (32.89%) of the study area. This class is widely distributed in the north and partially distributed in the south. The 'Suitable' suitability class, the second largest, covers 265.92 km<sup>2</sup> (31.58%). This class is spread from the center to the east and in the direction of the study area. The third suitability class is 'Very High suitable,' covering 142.92 km<sup>2</sup> (16.97%); it's distributed in the southern part. The fourth suitability class, 'Low Suitable,' covers 95.27 km<sup>2</sup> (11.32%), which is distributed from the western part to the center and east. The final suitability class, 'Unsuitable,' covers 60.36 km<sup>2</sup> (7.17%) spread across the western part of the study area, Table 11 and **Error! Reference source not found..**

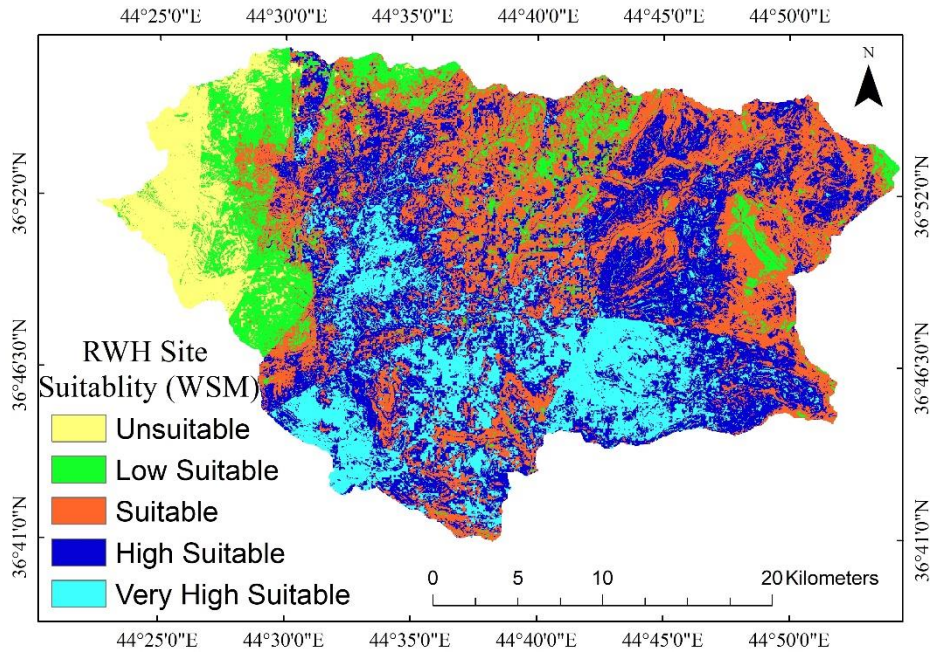


Figure 10: Final Suitability result of WSM

Table 11: Percentage of the area of the Suitability class of AHP and WSM

Class (Value)	Area of AHP (km <sup>2</sup> )	Area of AHP (%)	Area of WSM (km <sup>2</sup> )	Area of WSM (%)	Suitability Description
1	7.53	0.89%	60.36	7.17%	Unsuitable
2	62.43	7.39%	95.27	11.32%	Low Suitable
3	303.79	35.95%	265.92	31.58%	Suitable
4	466.63	55.22%	276.92	32.89%	High Suitable
5	0.012	0.0015%	142.92	16.97%	Very High Suitable

### 3.6 Comparison between two models

The comparison between AHP and WSM, illustrated in Figure 11 Shows that there are different performance indicators for each suitability class for each method. Using R-Square (R<sup>2</sup>), Root Mean Square Error (RMSE), and Standard Deviation (SD), they were compared to identify the best method. (Table 12).

Table 12: Comparison between two MCDA methods

MCDA Methods	R <sup>2</sup>	RMSE	SD
AHP	0.4524	0.1014	21.99
WSM	0.8069	0.0545	10.48

The findings indicate that WSM showed greater consistency and less variability than the other methods used. The  $R^2$  of WSM was very satisfactory. The lowest RMSE value for WSM indicates the smallest error, while a lower SD value signifies reduced data dispersion compared to the other two methods. Dispersion of WSM with two other methods.

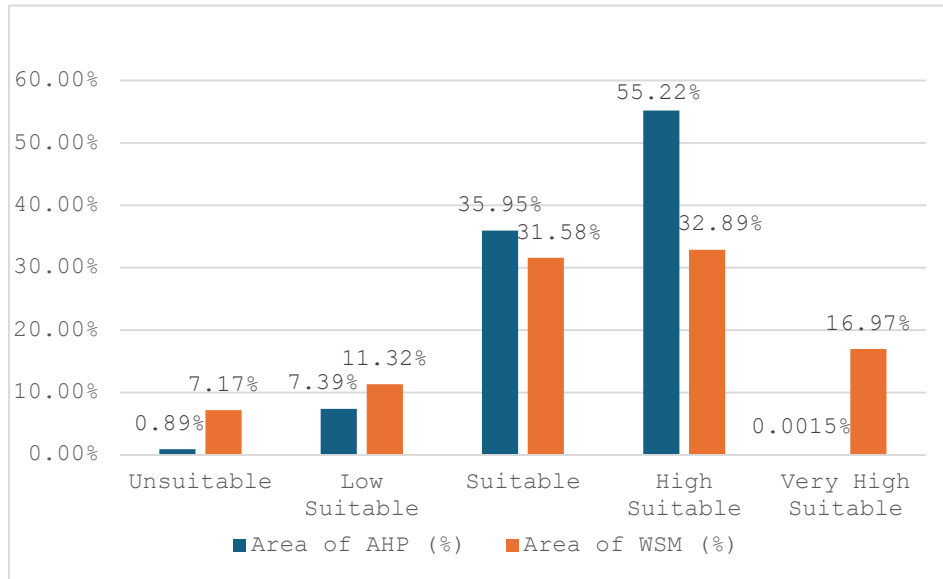


Figure 11: Compared percentage of suitability map between AHP and WSM

### 3.7 Dam Size Classification

The classification of dam construction features, such as outflow, geological and hydrological parameters, and the preprocessing of river basin and topographic data, is fundamentally complex [77, 78]. Meanwhile, a multitude of research has investigated size-based categorization. The height and storage of a dam were measured from the toe of the dam to the highest point where water could be stored, or crest. Various alternate definitions of classification are based on dimensions, including hazard potential, height, and storage capacity. [79, 80]. The classification of dams in Table 13.

Table 13: Dam size classification [23, 81, 82]

Category	Large	Medium	Small
Storage (S) (m <sup>3</sup> )	$S \geq 67,675,000$	$1,234,000 \leq S \leq 61,675,000$	$S < 1,234,000$
Height (H) (m)	$H \geq 30.5$	$12.50 \leq H \leq 30.5$	$< 12.50$

### 3.8 Suitable sites for RWH structure and Dam profile

The results of the WSM of MCDA indicate that stream order, drainage network, and contour lines at 10-meter intervals were used to identify three desirable locations for the dams. The dimensions of each dam, including length and height, have been determined by employing DEM. The three Dams located in the three different villages, Dam 1, Dam 2, and Dam 3, were located in Nawroin Village, Shekhan Village, and Leraban Village, respectively. Figure 12 and Table 14 Are present full details about of three proposed dams, such as the shape and location of the three suggested dams.

Table 14: Full Details of the three proposed dams

Dam ID	Location	Elevation sea level (m)	Dam size	Storage Capacity (m <sup>3</sup> )	Surface Area (m <sup>2</sup> )	Max. Depth of Dam (m)
Dam 1	36°42' N 44°35' E	827	Medium	3,960,937.50	281,939	40
Dam 2	36°43' N 44°33' E	688	Medium	5,467,187.50	304,622	40
Dam 3	36°47' N 44°33' E	792	Medium	6,941,406.25	329,829	37

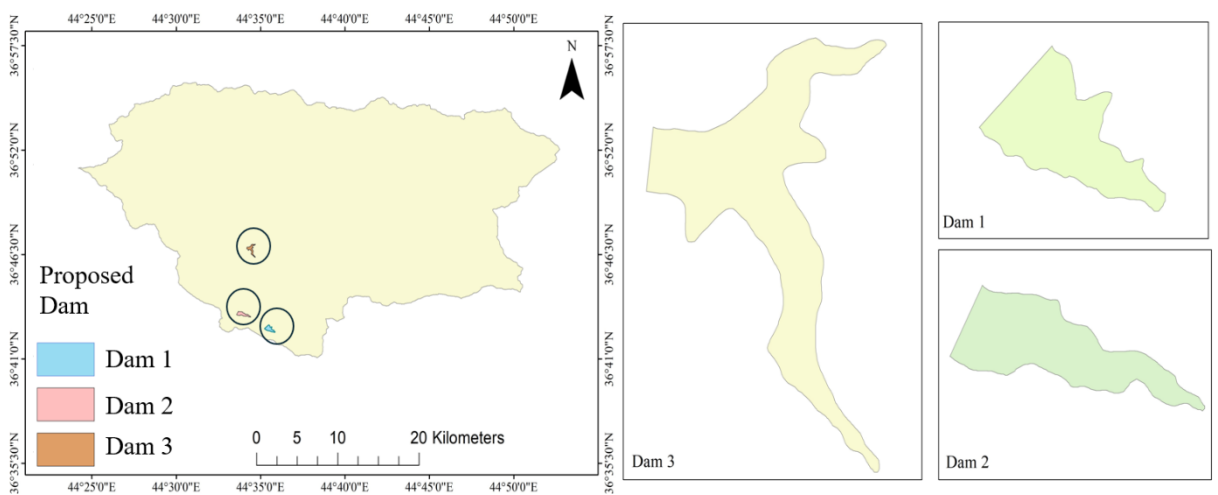


Figure 12: Shape and location of three proposed dams

### 3.9 Volume of Runoff

The runoff volume was calculated from the CN of the watershed extracted from the CN map (Figure 7 (F) to obtain the approximate volume of harvested water. The runoff produced by the catchments indicates that the locations proposed by the investigator are suitable for rainwater storage (Table 15) shows the runoff from the catchment area, with three scenarios of runoff (minimum, mean, and maximum runoff depths), providing three different runoff volumes.

Table 15: Runoff of the three catchment areas

Dam ID	Runoff (mm)			Catchment Area (km <sup>2</sup> )	Runoff Volume (m <sup>3</sup> )		
	Minimum	Mean	Maximum		Minimum	Mean	Maximum
Dam 1	308.76	413.7	603.85	<b>17.26</b>	5,329,196	7,140,462	10,422,451
Dam 2	372.45	640.2	708.81	<b>43.75</b>	16,283,514	27,989,544	30,988,736
Dam 3	606.17	687.99	740.92	<b>20.70</b>	12,547,719	14,241,393	15,337,044

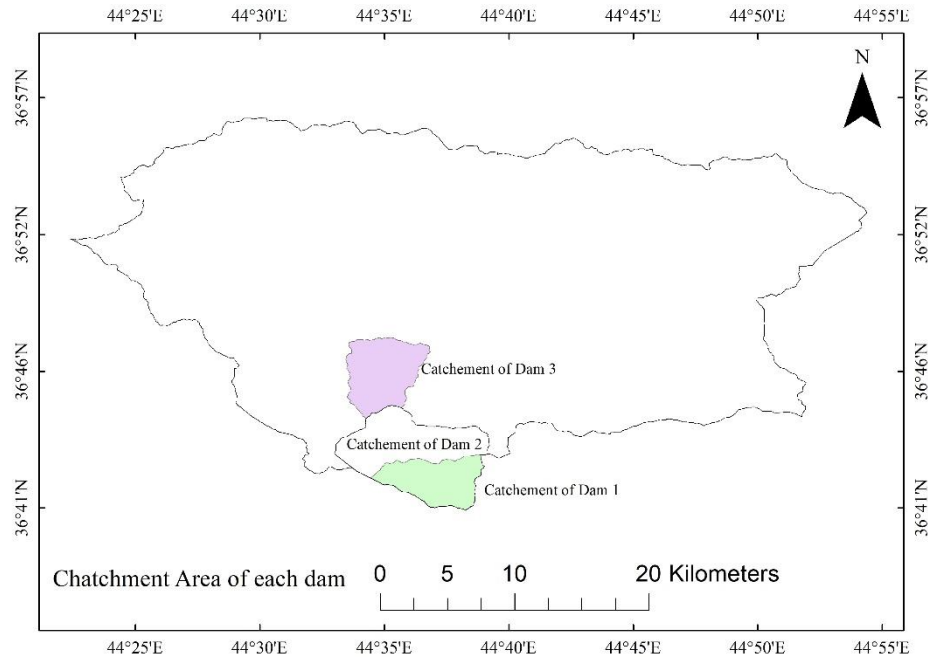


Figure 13: Catchment area of proposed dams

### 3.10 Solution for Urban Water Supply (Soran City)

Due to the problems faced by the water supply, including rapid population growth, old pipelines, poor management of the system, climate change, and drought, it was thought to find a sustainable solution, using rainwater and collecting it in the form of dams. According to the results of the study, the researcher can treat water shortages for most of the northern part of Soran for three months or more. The northern part of Soran needs 35,000 to 40,000 cubic meters daily, while Dam 1 provides 40,000 cubic meters under the minimum condition.

## 4. Discussion

The results of the research show that RWH is an important solution to the problem of water shortage in cities of the Kurdistan Region, particularly Soran. The GIS, RS, and MCDA will offer an effective method of determining the best places to install RWHs and areas that may be used to construct dams. The research applied the AHP and the WSM to test the applicability of the MCDA method in hydrological studies and to prove the relative reliability of the WSM, which is reflected by improved statistical performance indicators ( $R^2 = 0.8069$ ,  $RMSE = 0.0545$ ,  $SD = 10.48$ ). The suitability zones analysis revealed that approximately half of the study area was within high or very high suitability levels, indicating a strong potential for RWH deployment. This distribution pattern is consistent with the watershed's biophysical features, with precipitation, gradient, and soil texture playing crucial roles in runoff and infiltration. Sandy and loamy soils are found in certain subregions, thus allowing water to penetrate, whereas the clayey soils found in other regions prevent the water from running away. Such information can assist in decisions regarding the location of dam construction and the methods for conserving water on the surface. These findings are consistent with those of the rest of the world, which demonstrate the importance of considering the soil and land utilization when considering the feasibility of RWH.

The technological suitability of sites is also indicated through the socioeconomic aspects. The remote location of rivers reduces the risk of difficulties with the current watercourse, whereas proximity to

roads and villages ensures adequate access to facilities and recognition by the local population. The biophysical-socioeconomic tradeoff requires an all-inclusive approach to water resource management, whereby the efficiency in technology is not compromised with social and economic feasibility. The comparative study of AHP and WSM is a new item in the literature on regional water management. Though AHP has been useful in similar settings, WSM's better performance in this case suggests that simpler weighting methods may yield realistic results, provided the datasets are sufficiently strong. This conclusion disputes the point that more complicated decision-making models are inherently better; likewise, the idea that future studies should be more critical about the methodological decisions in the usage of MCDA. The study has shown that RWH, using specialized geospatial approaches, can successfully address water scarcity in Soran cities. The three proposed dam sites are options that can be considered by both the policymakers and engineers that offer a way to the long-term and sustainable water supply on the urban scale, the study area, characterized by its mountainous terrain and frequent topographical changes, is suitable for dam construction and environmentally friendly, as it occupies a small land area while simultaneously storing a large amount of water.

AHP with the WSM provides a rational, clear structure for water management in a territory where water shortages are acute. AHP is used to systematically break down complex problems into a hierarchical set of criteria, yielding relative weights that reflect hydrological and socio-economic priorities. WSM will then combine the weighted criteria into a composite score, allowing easy ranking of the interventions, like RWH sites. The achievement of subjectivity levels, enhanced consistency, and trade-offs were combined across rainfall variability, land use, slope, and community requirements. This combination method will be able to improve the effectiveness of planning in semi-arid areas and evidence-based policymaking, and offer a framework that can be replicated to guarantee the equitable distribution of resources. This research must be developed further to cover future climate change forecasts, socioeconomic trends, and profit and loss analyses to ensure that rainwater harvesting systems are resilient and adaptable in the area.

## 5. Conclusions

The research indicates that RWH has the potential to be a sustainable way of addressing urban water shortages in the Soran region of Iraqi Kurdistan. This study utilizes a combination of Geographic Information Systems, Remote Sensing, and Multi-Criteria Decision Analysis. Potential RWH zones are classified into five classes within the study area. Using the AHP and WSM methods, the suitability area outcomes for AHP are 0.0015%, 55.22%, 35.95%, 7.38%, and 0.89%, while the outcomes for WSM are 16.97%, 32.89%, 31.58%, 11.32%, and 7.17%. These percentages correspond to the suitability classes 'Very High suitable,' 'High suitable,' 'Suitable,' 'Low suitable,' and 'Unsuitable,' respectively, based on  $R^2$ , RMSE, and SD. The WSM is more reliable, appropriate, and consistent. The results of WSM for MCDA. The researcher employed stream order, drainage network, and contour lines at 10-meter intervals to determine suitable locations for medium-sized dams to implement the RWH system. The construction of one of these dams will meet the water needs of a portion of Soran city, specifically the northern area near the dam, thereby alleviating stress on Soran's water supply.

The analysis of the suitability zones indicated that almost half of the study area falls within high- or very-high suitability zones, indicating strong potential for RWH implementation. The results address short-term water supply issues while adding long-term resilience to climate fluctuations and urban development pressures. The three possible dam locations have provided policymakers, engineers,

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and planners with realistic recommendations and have served as a bridge to sustainable urban water management in the Kurdistan Region.

The RWH system ensures a sustainable public water supply. It alleviates the demand on existing water distribution infrastructure and is beneficial for the environment. Rainwater can help urban areas combat climate change. The Mediterranean Sea significantly influences the climate of the studied area. Summers are exceedingly hot and arid; however, winters are profoundly cold and wet. Temperature and precipitation fluctuate significantly across seasons and years. Elevation significantly impacts weather conditions. As one progresses northward, summers become briefer and more temperate. Winter introduces lower temperatures, increased precipitation, and snowfall. Soran City is mitigating water constraints in irrigation, agriculture, and water distribution through ongoing rainwater harvesting. To address the water deficit and preserve water for future generations, both the government and the public must endorse rainwater harvesting and utilization.

In addition to the technical outputs, the paper points out the need to integrate water resource strategies with the socioeconomic reality. The three variables of accessibility, community acceptance, and compatibility with the current infrastructure are the key to successful RWH endeavors. The holistic attitude to the issue below shows that sustainable water management entails the equilibrium between environmental suitability and social and economic viability.

Further studies should elaborate on this framework by applying it across various scenarios and economic feasibility analyses, incorporating these projections and models. These extensions will make the system of RWH more flexible and adaptable to the changing demographic and environmental conditions. Finally, the research paper will add to the existing literature that RWH, as one of the tools supported by GIS, RS, and MCDA, can be a backbone of sustainable water supply in urban areas in arid and semi-arid conditions.

## **6. Recommendation**

The suggestion of constructing a dam is one of the solutions to the water shortage in this region. The topography of the area is very favorable for the construction of a large-volume dam occupying a small land area.

### **Author's Contribution**

Conceptualization, Methodology, and Modeling were carried out by Muhammad Ismael Kak Rasool, and supervision was provided by Hassan Mohammed Hameed.

### **Conflict of Interest**

The author declares no conflicts of interest. This research was conducted independently, without any commercial or financial involvement

### **Use of AI tool Declaration**

The authors declare that any AI tools used in the preparation of this manuscript were limited to language and readability improvement only, and were not used to generate scientific content, data, analyses, or conclusions, with full responsibility retained by the authors.

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