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Delineation of Potential Rainwater Harvesting Sites Using a GIS-Based Decision Support System in a Semi-Arid Region of Pakistan: A Study of District Dir Lower, Pakistan

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Abstract: *Water is considered one of the most remarkable natural resources essential for life. Due to multiple usages and the severe shortage of water in some parts of the world, rainwater harvesting (RWH) methods have been recommended for alleviating drought conditions. The prime purpose of this study is to explore suitable locations where rainwater harvesting structures can be implemented for efficient water management in district Dir Lower. Geographical information system (GIS) with a multi-criteria decision analysis approach (MCDA) was utilized for RWH site selection, based on soil texture, land use land cover (LULC), rainfall, runoff potential, drainage density, slope, lineament density, and geology. Weighted overlay analysis was used for identifying potential RWH locations by applying weight to each influencing parameter. Analytical Hierarchy Process (AHP) was used to allocate weight to each criterion. The study area was classified into five suitability zones; highly suitable, suitable, moderately suitable, less suitable, and not suitable. The weighted overlay analysis suggests that 5.51%, 52.19%, 31.12%, 8.20%, and 2.98% of the study area is not suitable, less suitable, moderately suitable, suitable, and highly suitable for rainwater harvesting respectively.*

***Keywords**: Rainwater harvesting, MCDA, weighted overlay analysis, suitability zones, AHP*

1. Introduction

Water consumption is increasing as the global population grows, and water is used in the agricultural sector, industries, and domestic, among numerous other uses, putting water under strain (Ahmed et al., 2020). Water scarcity is a global issue, especially in underdeveloped countries (dos Anjos Luís & Cabral, 2021). Although most countries receive sufficient rainfall, there is a lack of water management, with most precipitation overflowing instead of being stored properly (Kolekar et al., 2017). Aside from that, traditional water conservation and land use practices (Shah et al., 2011), poor rainwater management, and farmers' limited ability to successfully address water requirements impair crop output, particularly in rain-fed agriculture (Alwan et al., 2020; Lin et al., 2015). Various water management approaches have been employed around the world to address these water concerns (Oweis & Hachum, 2006). Rainwater harvesting (RWH) has been utilized for thousands of years to mitigate water scarcity, lower soil erosion rates, and limit the incidence of floods and groundwater recharge in a variety of climates (Tolossa et al., 2020). Furthermore, RWH is used to mitigate the negative impacts of climatic variability in areas where droughts and dry spells are frequent (Kattel, 2022).

However, identifying viable RWH sites is difficult because of the volume of water captured from the watersheds and the need to minimize ecological harm in a given area(Wu et al., 2021). According to Jaramillo et al. (2020), vegetation cover, soil type, watershed topography, rainfall intensity and quantity, and runoff potential, all influence the selection of possible RWH sites. Wu et al. (2018) proposed important parameters such as LULC, runoff capacity, slope, soil texture, proximity to farmland, and roads for locating RWH locations. Ejegu and Yegizaw (2020) identified six important parameters, i.e. soil texture, LULC, rainfall quantity, slope, drainage density, and proximity to settlements.

According to Mahmoud and Alazba (2015), hydrologic models combined with Geographic Information Systems (GIS) are commonly utilized to locate potential RWH sites. According to Ghani et al. (2013), 60% of Pakistan's population lives in hilly and rural areas, where ensuring the execution of water conservation projects are costly, resulting in delayed agricultural development. District Dir Lower is located in Pakistan's northwestern region, and it is characterized by small mountain valleys. The study area's annual precipitation is sporadic and insufficient for agriculture, resulting in food insecurity. There is no appropriate management of rainwater storage to meet agricultural water requirements.

The widening gap between irrigation water availability and agriculture water requirements in the study area has an impact on agricultural development, resulting in local food insecurity. Considering the prevailing changing climatic conditions in the research area, rainwater storage for agricultural, residential, and animal use is of critical importance. In these circumstances, alternative methods of water management such as agricultural rainwater harvesting (ARWH) are quite beneficial in the research area. Keeping in view, the current study is aimed to identify possible areas for effective ARWH implementation using an integrated GIS-based Multi-Criteria Decision Analysis (MCDA) technique.

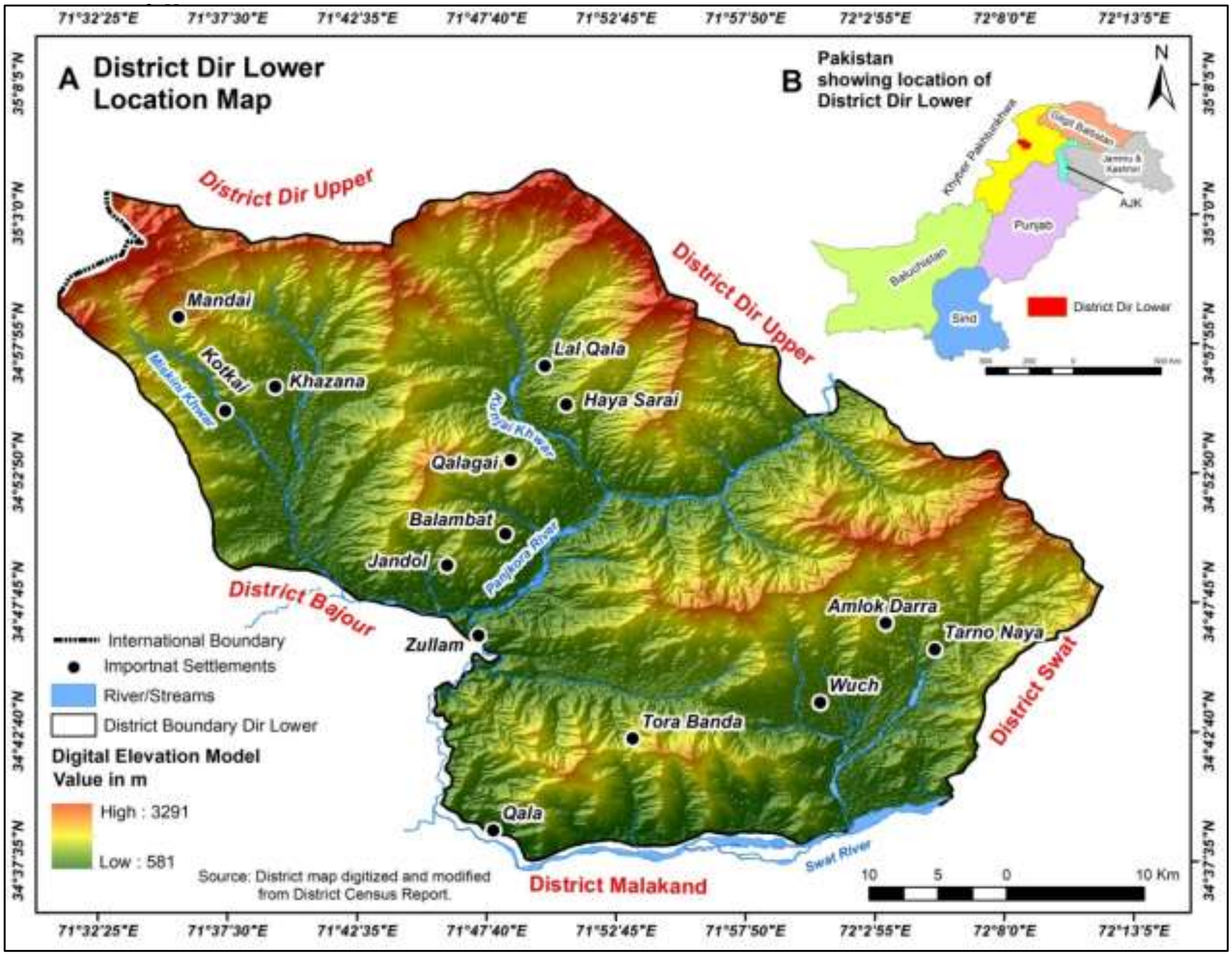
2. Materials and Methods

2.1. Study Area

This study area, district Dir Lower occupies an area of 1734.58 km^2 and is located in northern Pakistan. Geographically, it is located between 34º 37' 35″ to 35º 03' 05″ north latitudes and 71º 32' 35″ to 72º 08' 03″ east longitudes (Ullah et al., 2014). Upper Dir borders the study area to the north, Bajaur district and Afghanistan to the west, and Malakand district to the south. District Swat is located in the east of the study area (Figure 1). The study area's altitude ranges from 581 to 3291 m. The annual average rainfall and temperature are 1186 mm and 16 °C, respectively (Sarwar et al., 2021). The research region has a diverse landscape that includes mountains, hills, gorges, and intermountain plains.

2.2. Data Acquisition and Analysis

The influencing parameters used in the current study include rainfall, drainage density, runoff potential, soil texture, slope, lineament density, geology, and LULC. Remote sensing data was obtained from various internet sources which were subsequently used to delineate ARWH locations in the study area. Drainage density, lineament density, and slope were calculated from SRTM DEM at 30 m resolution. To determine the LULC of the research region, ESA Sentinel-2 imagery for the year 2022 with 10 m resolution was acquired from the Copernicus Open Access Hub website. The imagery was classified into various LULC classes using the maximum likelihood classifier algorithm in the ArcMap 10.8 environment. For the calculation of potentiality, the rainfall data of the study area and surrounding five meteorological stations (Dir Upper, Balambat, Malam Jabba, Saidu Sharif, and Kalam) was acquired from the Pakistan Meteorological Department, Regional Office Peshawar. The acquired data was interpolated and the rainfall potentiality was computed.



Source: District map digitized and modified from District Census Report.

Figure 1. Location map of the study area

The hydrological soil group data developed by the United States Department of Agriculture (USDA) was downloaded from *https://daac.ornl.gov/about/*. The HSG data is available at a spatial resolution of 250 m, which was resampled to 30 m to be compatible with the remainder of the dataset. The HSG data is generated to enhance USDA curve-number (CN) runoff modeling at both the local and regional scales (Prasad et al., 2014). The Runoff Curve Number (CN) approach, created by the United States Soil Conservation Service (UNSCS), is a methodology for predicting anticipated runoff after a heavy downpour (Verma et al., 2021). The CN estimates probable runoff based on the LULC type and hydrologic soil group (HSG). The global soils are classified into four HSGs (A, B, C, and D) based on the lowest infiltration rate observed for bare soil after an extended soaking time. The geological map of the study area was acquired from the Geological Map of Northern Pakistan edited by Searle and Asif.

The agricultural water poverty index (AWPI) mainly consists of five major components namely; resources, usage, capacity, access, and environment (van der Vyver, 2013). These major components are divided into 17 sub-components. The data regarding all these sub-components and indicators was collected through a questionnaire survey including questions about all these parameters. A union council-wise household survey was conducted in the study area. 05 respondents were selected from each union council. Respondents were selected randomly and priority was given to long-term farmers. The collected data was normalized by using Equations 1 and 2 (Nasir et al., 2020).

$$\text{Index} = 4X\ \frac{X-Xmin}{Xmax-Xmin} + 1\text{……………….Eq. 1}$$

$$\text{Index} = 4X\ \frac{X-Xmax}{Xmin-Xmax} + 1\text{……..…………Eq.2}$$

$$Where\ the\ index\ is\ Resources\ (R), Use\ (U), Capacity\ (C), Access\ (A), and\ Environment\ (E), X\ actual\ value\ of\ each\ AWP\ parameter, Xmax =\ Highest\ value\ sub - component, Xmin =\ Lowest\ value\ sub - component$$

The WPI was calculated by combining the five major components mentioned above as proposed by (Lawrence et al., 2002). Each sub-component's ranking score for each UC was added together and the commutative ranking score was divided into five AWP classes: No AWP, Low AWP, Moderate AWP, High AWP, and Very High AWP. The UC-specific AWPI map was then created in ArcMap 10.8. Equation 3 shows the WPI overall value for a specified UC as reported by Lawrence et al. (2002) and Nihila et al. (2012).

$$AWPI = RR + RA + RU + RC + RE\ \ \text{……………………………..Eq.3}$$

$$Where\ AWPI\ is\ the\ calculated\ Agriculture\ Water\ Poverty\ Index, RR\ rank\ of\ component\ Resource\ (R1R2\ R3), RA\ rank\ of\ component\ Access\ (A1 + A2 + A3 + A4), RU\ rank\ of\ component\ Use\ (U1 + U2\ U3\ U4),. RC\ rank\ of\ component\ Capacity\ (C1 + C2\ C3)\ and\ RE\ rank\ of\ component\ Environment\ (E2 + E3)$$

2.3. Selection of ARWH Sites

Researchers have proposed several strategies and techniques for identifying possible RWH sites. The majority of these strategies and methodologies use the Analytical Hierarchy Process (AHP), a GIS-based multi-criteria decision-making approach (Jafari et al., 2018), that incorporates various socioeconomic and environmental considerations. AHP is a multi-criteria decision analysis (MCDA) that researchers frequently advocate (Krois & Schulte, 2014; Singh et al., 2017). The AHP approach is used to characterize an issue, design an AHP hierarchy, create a pair-wise comparison matrix, calculate relative weight, assess consistency, and determine total weights and overall ratings (Safari et al., 2010). The approach is endorsed by scholars working in several fields. In the present investigation, the AHP established by Saaty in 1980 (Saaty, 1980) was utilized for identifying the potential RWH sites.

2.4. Pair-wise comparison matrix

The pair-wise comparison matrix is generated using Saaty's (1986) fundamental scale of relative importance, as illustrated in Table 1. In the comparison procedure, values ranging from 1 to 9 are used to indicate the degree of importance of one element over another factor based on the parameter being selected for analysis (Saaty, 2008).

Table 1. Relative Importance of Criteria (Saaty, 1987)

Intensity of Importance	Definition	Description
1	Equal important	Two criteria of equal importance concerning the goal.
3	Moderately important	Moderately importance of one criterion over other criteria.
5	Strongly important	Judgments strongly favor one criterion over another.
7	Very strong important	A judgment is very strongly in favor of one criterion over other criteria.
9	Extremely important	Showing the extreme importance of one factor over another affects the other concerning goal.
2, 4, 6, 8	Intermediate values	In case of compromises needed.

2.5. Assignment of Weightage to Different Parameters

Following the determination of the parameter weights, all components were assigned to a single assessment scale before performing weighted overlay analysis in ArcMap, spatial analyst 10.8. The major influencing parameters were weighted using AHP. The score was assigned to all the parameters on a scale from 1 to 5 based on their suitability and effectiveness in identifying suitable sites for RWH. A score of 5 on the parameter is considered highly suitable and a score of 1 shows not suitable conditions (Shadeed et al., 2020).

The resultant map featured a layer identifying potential ARWH locations in the study region, which were divided into five appropriateness classes: not suitable, less suitable, moderately suitable, suitable, and highly suitable. The method is depicted in Figure 2.

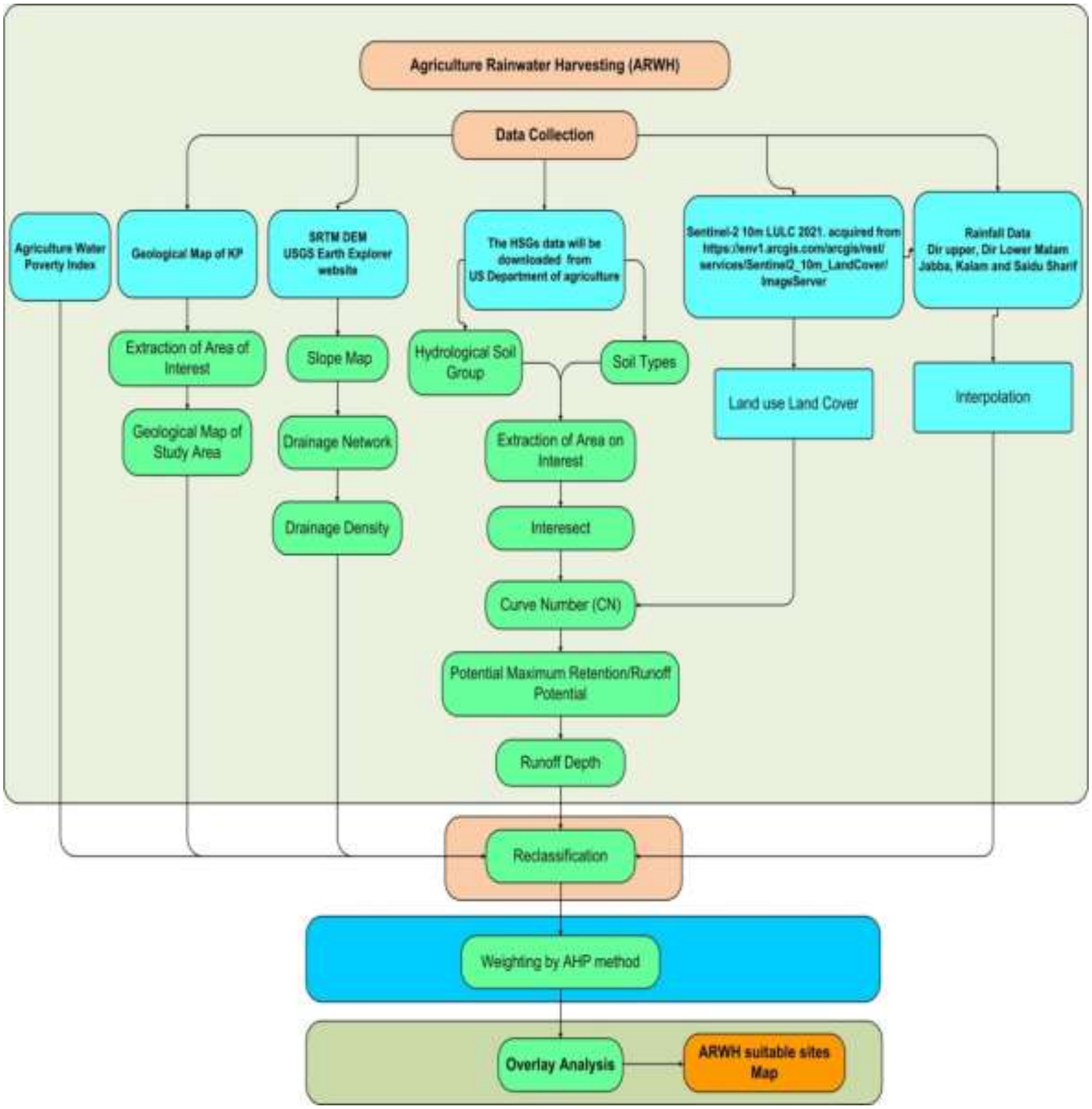


Figure 2. Methodology Flow Chart for delineation of Agriculture Rainwater harvesting Sites

3. Results and Discussion

3.1. Results

Eight influencing parameters, including rainfall, drainage density, runoff capacity, slope, soil texture, lineament density, geology, land use, land cover, and agriculture water poverty index (AWPI), were used to identify prospective rainwater harvesting locations in the research area. The spatial distribution of the individual parameters and their influence on site selection are discussed below.

3.1.1. Land Use Land Cover (LULC)

LULC plays an important role in evaluating the viability and effectiveness of rainwater harvesting (RWH) site selection. The types and extent of LULC determine the amount of rainwater that can be collected, stored, and used (Jedhe, 2014). The acquired sentinel-2 image was classified into six LULC classes. Figure 3A depicts the spatial distribution of these LULC classes. The analysis reveals that the primary LULC types were rangeland (53.18%), cultivated land (9.83%), build-up area (24.17%), water (0.51%), vegetation (12.22%), and barren land (0.09%) (Table 2). The rainwater harvesting appropriateness of each LULC class was determined using the multi-criteria decision analysis (MCDA) approach Analytical Hierarchy Process (AHP).

The water and built-up regions were deemed unsuitable for rainwater harvesting site selection, as per the literature that is currently available; consequently, they were assigned AHP weights of 0.03. For rainwater collection, rangeland with a weight of 0.29 and forests with a weight of 0.08 are considered suitable and less suitable, respectively. It was determined that agriculture and cultivated land (0.13) are moderately suitable for collecting rainwater (Wondimu & Jote, 2020). According to Mosase et al. (2017) and Toosi et al. (2020), barren land with undulating topography is appropriate for RWH locations because of increased runoff and less infiltration. Figure 3B depicts the spatial distribution of various LULC suitability for RWHS site selection. Table 2 depicts the LULC sub-classes, the area under each class, assigned AHP weight, and their effectiveness in RWH site selection.

3.1.2. Hydrological Soil Groups (HSGs) or Soil Texture

Soil texture is an important factor in evaluating the appropriateness and efficacy of rainwater collection site selection. Soil texture, defined as the proportion of sand, silt, and clay particles in the soil, has an impact on infiltration rate, water retention capacity, and overall soil structure. These characteristics have an impact on how effectively rainwater may be collected, stored, and used.

HSGs, in combination with LULC and curve number (CN), are commonly employed to quantify rainfall runoff potential. HSGs are comprised of types A, B, C, and D, which indicate low, moderately high, high, and very high runoff potential. The obtained data was in Geo TIFF format, which Arc Map 10.8 supports. Using the acquired data, a map of the research area's runoff potential was created to select RWH sites. According to the HSG statistics, the research region is divided into two HSG types i.e. "C" and "CD". The soil texture of class C is defined by <50% sand and 20-40% clay with moderately high runoff potential, accounting for 89.68% of the total area. Class "CD" soil is composed of <50% sand and >40% clay, resulting in strong runoff potential and accounting for 10.32% of the total area. Soil with a high percentage of clay particles is considered desirable for RWH site selection, because of its great water-holding capacity, whereas soil with comparatively low clay and high sand content is considered unfit due to the high rate of infiltration (Chimdessa et al., 2023; Wondimu & Jote, 2020). Soleri et al. (2019) observed that soil groups D and CD create significant runoff while also having good water retention power, making them ideal for RWH in a given location. The AHP determined weight for HSG type CD is 0.75, while C has 0.25. Table 2 depicts the soil sub-classes, the area under each class, assigned AHP weight, and their effectiveness in RWH site selection.

3.1.3. Drainage Density

Drainage density, defined as the total length of all streams and rivers in a drainage basin divided by the basin's total area, is an important hydrological characteristic that influences the selection of rainwater harvesting (RWH) locations (Jha et al., 2014; Wondimu & Jote, 2020). Understanding drainage density is useful for assessing the possibility of water collection, infiltration, and storage (Setiawan & Nandini, 2022). The study area's stream network was derived from the SRTM DEM using Arc GIS hydrology tools, as utilized by Mugo and Odera (2019). The derived drainage network was subsequently used to create the drainage density map of the study area. The drainage density of the research area was divided into five classes with equal intervals. The drainage density in the studied area varies from <0.5 to >2.5. The analysis reveals that the majority of the study area has low drainage density < 0.5 which accounts for 55.92% of the total area.

The drainage density classes were assigned the suitability weight based on the AHP Method (Saaty, 1987). The AHP weight of various drainage density classes varies from 0.04 to 0.62. Areas with higher stream density are considered highly suitable for RWH as compared to areas with low drainage density. The drainage density class > 2 was highly suitable with an AHP weight of 0.62, whereas the drainage density class < 0.5 with an AHP weight of 0.04 was considered not suitable for RWH. Table 3 depicts the drainage density classes and their relative effectiveness in identifying the RWH sites and Table 4 depicts the AHP weight assigned to various classes. Figure 4A illustrates the spatial distribution of various drainage density classes and Figure 4B depicts the spatial distribution of AHP weight of drainage density classes across the study area. Table 2 depicts the drainage density sub-classes, the area under each class, assigned AHP weight, and their effectiveness in RWH site selection.

3.1.4. Rainfall Potential

Rainfall is an essential component in the successful operation of rainwater collection systems. It has an impact on water availability, system design, runoff generation, infiltration, and overall system performance (Ejegu & Yegizaw, 2020). Planners and engineers may optimize the placement and design of RWH systems by carefully evaluating rainfall patterns, intensity, and distribution to maximize water capture, improve groundwater recharge, control erosion, and promote sustainable water management practices. The quantity, intensity, and distribution of rainfall have a direct impact on the amount of water that can be collected and stored, which in turn influences the effectiveness and long-term reliability of rainwater harvesting (RWH) sites.

The rainfall data of five meteorological stations was interpolated by applying the Kriging interpolation tool in the ArcMap Spatial Analyst environment. The interpolated surface is then was classified into five rainfall classes (<200 mm, 201-400 mm, 401-600 mm, 601-800 mm, and >800 mm) employing an equal interval classification method. Figure 4C illustrates the spatial distribution of rainfall in the study area. Rainfall of >800 mm can be observed in a small area in the southeastern part of the study area. The rainfall amount decreased towards the west and northwest of the study area.

Using the AHP approach suitable weights were assigned according to RWH prospects translating various classes into not suitable, less suitable, moderately suitable, and highly suitable for identification of RWH sites. The AHP weight of various rainfall classes varies from 0.04 to 0.62. The maximum AHP weight was assigned to rainfall class 601-800 mm, which covers an area of 1493.1 km^2 (86.10%) and represents suitable conditions for delineation of the RWH site. The rainfall classes; 201-400mm, 401-600mm, and 601-800mm with weights values of 0.08, 0.11, and 0.15 were considered less suitable, moderately suitable, and suitable respectively. Table 2 depicts the rainfall sub-classes, the area under each class, the assigned AHP weight, and their effectiveness in RWH site selection. Figure 4D illustrates the spatial distribution of AHP weight values across the study area related to rainfall.

3.1.5. Slope

The slope is an important factor in the effective and efficient identification of rainwater harvesting site selection. The slope of an area affects the water flow, runoff patterns, erosion management, infiltration rates, and design of RWH structures. Slope information is crucial to maximize water capture, improve groundwater recharge, avoid soil erosion, and support sustainable water management techniques. The steeper the slope, the less suitable the location for RWH since steep slopes demand considerable capital for dam building and are prone to flooding. On the contrary, the moderate to gentle slope slows runoff and allows water to be easily stored in surface structures on low cast (Oboko et al., 2021).

The slope of 0-10º is particularly suitable for the potential RWH site selection. The slope map of the study area was derived from the SRTM digital elevation model (DEM). The derived slope was subsequently classified into five slope classes i.e. 0-10º, 10.1-20º, 20.1-30º, 30.1-40º, and >40º. Figure 5A illustrates the spatial distribution of various slope classes across the study area. The analysis of Figure 5A reveals that 29.44% of the study area has a moderate to gentle slope i.e. 10.1-20°, followed by <10° slope which accounts for 28.89% of the total area.

The derived slope classes were assessed for their effectiveness in RWH site selection through AHP analysis. The AHP weight assigned to <10° slope is 0.50 due to its major contribution to RWH site selection. The weight assigned to the slope class of >40.1° is 0.03 which is deemed not suitable for rainwater harvesting site selection. The analysis reveals that 28.89 % of the study area is highly suitable for RWH intervention. Table 2 depicts the slope sub-classes, the area under each class, assigned AHP weight, and their effectiveness in RWH site selection

3.1.6. Runoff Potential

Runoff potential is an important consideration when choosing a site for RWH. It influences the quantity as well as accessibility of water which can be captured and stored during a storm event. Evaluating an area's runoff potential assists in designing effective RWH systems that maximize water capture while ensuring sustainable water management. Runoff potential of the study area was computed using the LULC type and hydrologic soil group (HSG) (Prasad et al., 2014). The runoff potential map of the study area was classified into five runoff potentiality classes i.e. <75, 76-81, 82-85, 86-93, and >94. Figure 5C illustrates the runoff potential map of the study area. The analysis of Figure 5C reveals that a smaller area (8.82 km^2) has a runoff potential more than 94, whereas 923.73 km^2 (53.27% of the entire study area) has a runoff potential between 86 and 93. The runoff potential classes and AHP weights have a direct proportional relationship. AHP weight increases with runoff potentiality, and vice versa. The AHP weights computed range from 0.03 to 0.52. According to Nyirenda et al. (2021), sites with a high amount of runoff are ideal for RWH, while places with low runoff potential are unsuitable. As a result, the maximum weight of AHP indicates an optimum position for rainwater gathering. The runoff potential class of >94 with an AHP weight of 0.52 is considered highly suitable for rainwater collection, while runoff potential classes <75 with an AHP weight of 0.03 are not suitable. Runoff potential class 86-93 is suitable for rainwater gathering locations. Figure 5D illustrates the runoff potential appropriateness for RWH site selection based on the weight calculated through the Analytical Hierarchy Process (AHP). The analysis suggests that just 0.51% of the study area having runoff potential of >94 is highly suitable, while 12.22% of the overall study area is not suitable for rainwater collection sites. The largest area (53.27%) of the overall study area with a runoff potential 86-93, and an AHP weight of 0.26 is suitable, whereas 13.77% and 20.23% are moderately and less suitable for rainwater harvesting site selection respectively. Table 2 depicts the runoff potential sub-classes, the area under each class, assigned AHP weight, and their effectiveness in RWH site selection

3.1.7. Geology

Geology and lithology are important considerations when selecting a rainwater harvesting site. Geology has an impact on infiltration rates, water storage capacity, water quality, and structural stability in RWH systems (Bera et al., 2020). The geology of the study area is composed of nine different rock types and formations these include Melange zone (MZ), Mesozoic meta-sedimentary rocks with protoliths, carbonate and clastic and meta-sedimentary rocks (MMRPCCMSR), Gilgit complex meta-sedimentary rocks (GCMR), Palaeozoic meta-sedimentary rocks (PMR), Kamila amphibolite complex (KAC), Ultra volcanic, rhyolite, volcanic-clastic sedimentary rocks (UVRVSR), Chilas complex mafic-ultramafic stratiform plutonic complex (CCMUSPC) and Ambela granodiorite, alkali granite pegmatite and microgranite (AGAGPM). Figure 6A illustrates the spatial distribution of various rock types and geological formations. The Gilgit complex metasedimentary rocks cover an area of 30.26 km^2 (1.74% of the overall studied area), while the Kamila amphibolite complex covers the largest area of 694.5 km^2 (40.04% of the study area).

According to the expert opinions the CCMUSPC, CGDGG, and AGAGPM are highly suitable for rainwater harvesting. The area under these classes accounts for 647.71 km^2. Mélange zone (MZ) with rank 5 which is not suitable for rainwater harvesting covers 3.23% of the total study area. The three geological units PMR, KAC, and UVRVSR with moderate to high water retention capacity cover an area of 875.61 km^2. The geology class MMRPCCMSR and GCMR are low and moderately suitable for RHW intervention. Table 2 depicts the geology sub-classes, the area under each class, the assigned AHP weight, and their effectiveness in RWH site selection. Figure 6B illustrates the weight value of various geological units assigned by the Analytical Hierarchy Process.

3.1.8. Lineament Density

Lineaments are the concentration of linear features on the Earth's surface that are usually suggestive of subsurface geological structures including faults, fractures, joints, and other structural discontinuities. These linear characteristics are often derived through remote sensing, using satellite imageries. Lineaments frequently regulate the flow of both surface and groundwater, making it a fundamental parameter for RWH site selection and other hydrogeological investigations (Oboko et al., 2021). Lineament density is the number of these linear features per km^2.

For digitization of lineaments, the DEM was displayed with four different sun azimuths for 0°, 45°, 90°, and 135°: angles keeping the input value of sun altitude the same at 45°. Then, all of the images resulting from the hill shade process were overlaid to get the DEM imagery that was observed from different angles of azimuth (Abdullah et al., 2010) and consequently, digitize the linear features from each DEM image as lineaments. The line density tool of ArcMap

The lineament density is indirectly propositional to its suitability for the RWH site selection. The higher the lineament density, the greater the water infiltration and low water retention potential, resulting in lower suitability for RWH. The lineament density of the study area varies from 0.811 to 4.05 which were classified into five classes i.e. 0-0.811, 0.812-1.62, 1.63-2.43, 2.44-3.24, and 3.25-4.05. Figure 6C illustrates the spatial distribution of various lineament density classes across the study area. The analysis reveals that the largest area is covered by a lineament density class of 1.63-2.43 i.e. 43.79% of the study area.

The AHP weights of the lineament density classes range from 0.03 to 0.50, with the class with the lowest weight being more suitable for RWH site selection. Figure 6D depicts the regional distribution of weight values for different lineament density classes based on AHP. The lineament density class 0-0.811, with AHP weight 0.03, is unsuitable for rainwater collection because it lets water infiltrate and has a low water retention capacity. According to expert opinions, the lineament density class 0.812-1.62 with AHP weight 0.50 is ideal for rainwater gathering. This class covers 16.60% of the total area. The lineament density class 0.812-1.62 is suitable for RWH with AHP weight 0.26, covering 27.69% of the entire study area. Table 2 depicts the lineament density sub-classes, the area under each class, assigned AHP weight, and their effectiveness in RWH site selection

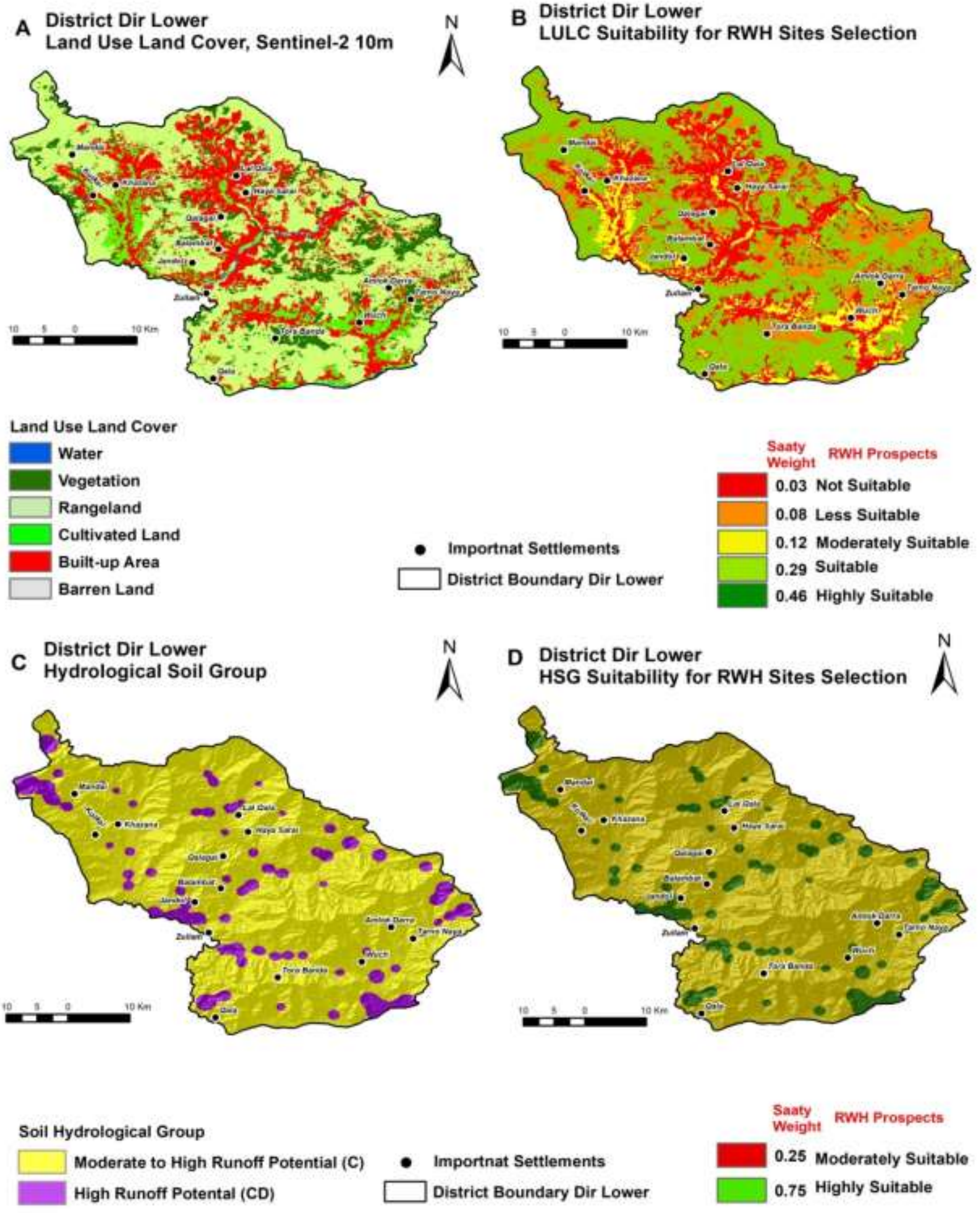


Figure ***(3A)*** illustrates the spatial distribution of various LULC classes in the study area ***(3B)*** LULC suitability classes for RWH site selection based on weight assigned by AHP ***(3C)*** illustrate the HSG distribution in the study area ***(3D)*** illustrate the HSG appropriateness for RWH site selection based on the weight calculated through Analytical Hierarchy Process (AHP).

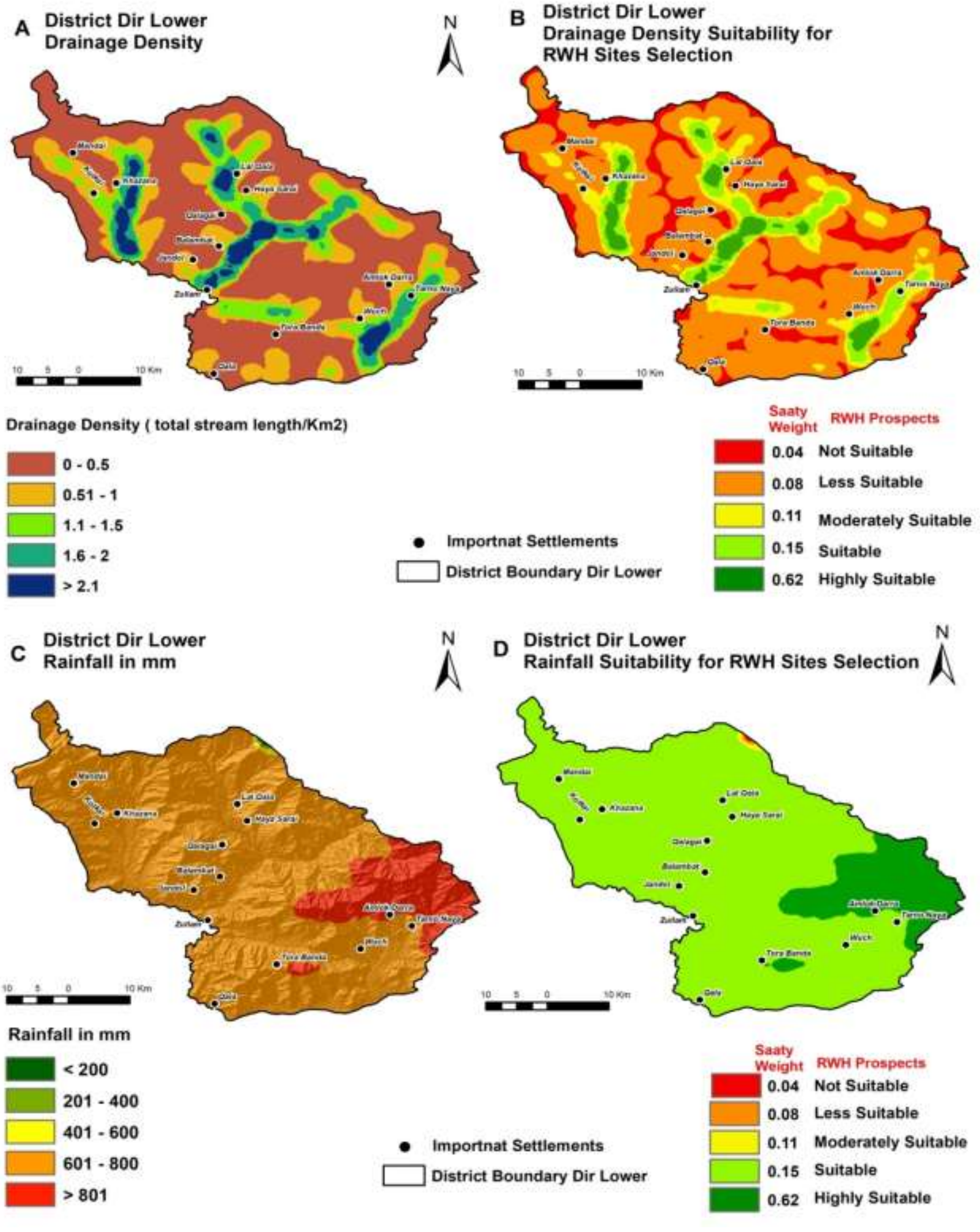


Figure ***(4A)*** illustrates the spatial distribution of various drainage density classes in the study area ***(4B)*** Drainage density suitability classes for RWH site selection based on weight assigned by AHP ***(4C)*** illustrates the rainfall distribution in the study area ***(4D)*** illustrates the rainfall appropriateness for RWH site selection based on the weight calculated through Analytical Hierarchy Process (AHP).

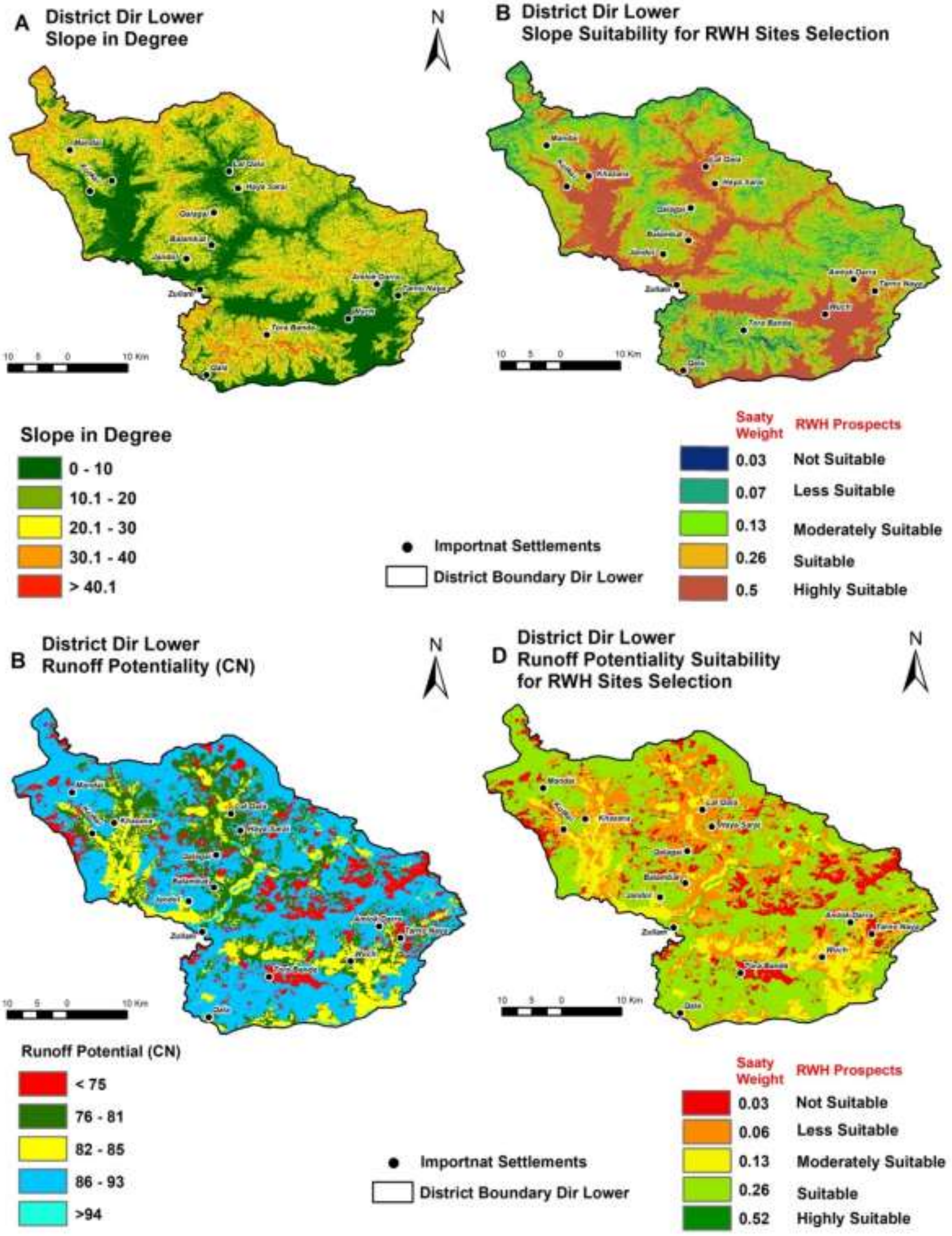


Figure ***(5A)*** illustrates the spatial distribution of various slope classes in the study area ***(5B)*** Slope suitability classes for RWH site selection based on weight assigned by AHP ***(5C)*** illustrate the runoff potentiality of the study area ***(5D)*** illustrates the runoff potential appropriateness for RWH site selection based on the weight calculated through Analytical Hierarchy Process (AHP).

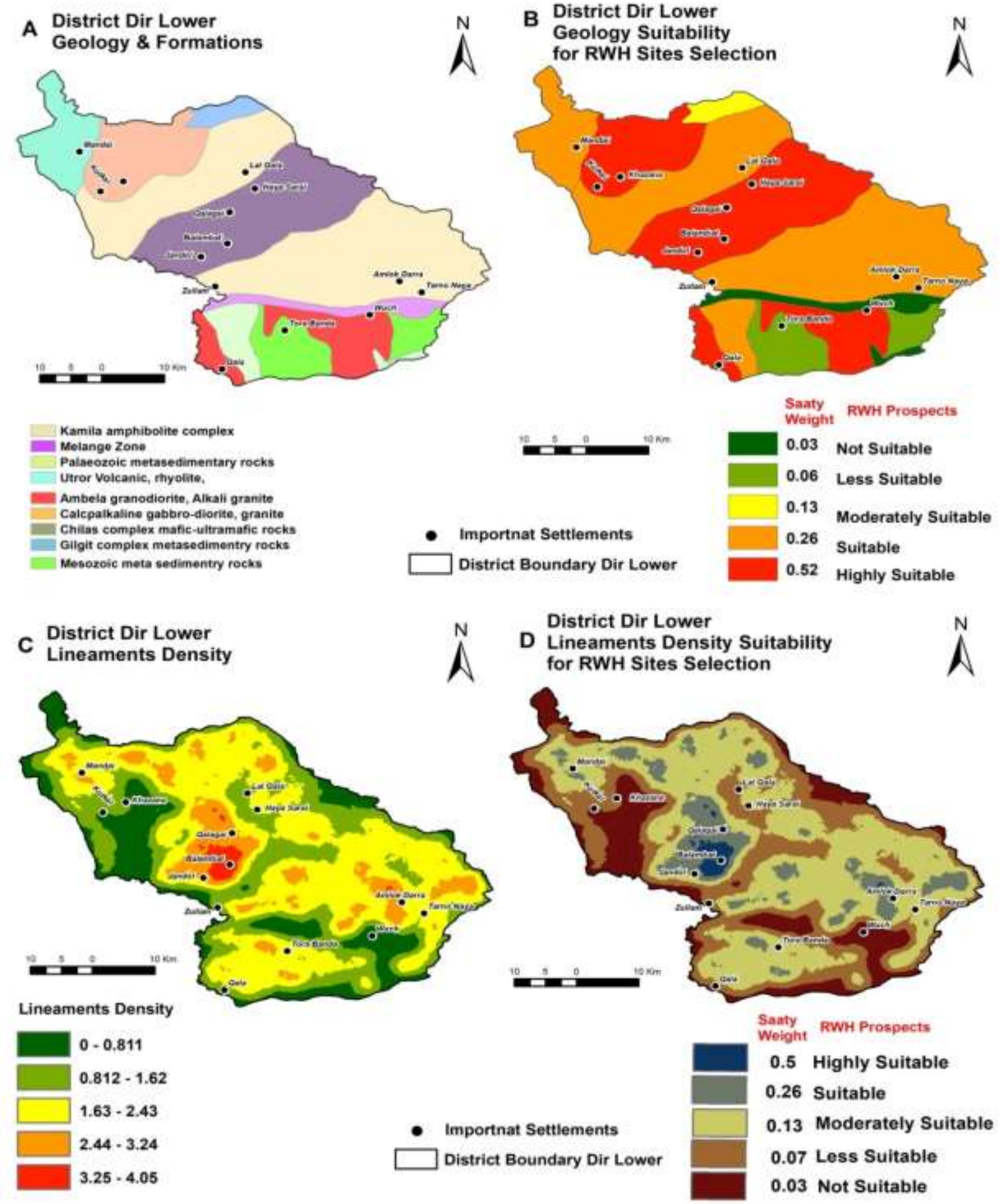


Figure ***(6A)*** indicates the spatial distribution of geological formations in the study area ***(6B)*** Geology suitability classes for RWH site selection based on weight assigned by AHP ***(6C)*** highlights the Lineaments density of the study area ***(6D)*** shows the Lineaments density appropriateness for RWH site selection based on the weight calculated through Analytical Hierarchy Process (AHP).

Table 2. Sub-parameters Classes, the Area under each class, their AHP weight, and their effectiveness in RWH site selection

Factor	Area (Km^2)	%age Covered Area	AHP Weight	RWH Prospects
Rainfall Potential (mm)				
<200	0.48	0.09	0.04	Not suitable
201-400	1.14	0.13	0.08	Less suitable
401-600	3.34	0.39	0.11	Moderately suitable
601-800	1493.1	86.10	0.15	Suitable
>800	230.53	13.29	0.62	Highly suitable
Runoff Potential				
<75	211.92	12.22	0.03	Not suitable
76-81	350.97	20.23	0.06	Less suitable
82-87	238.88	13.77	0.13	Moderately suitable
88-93	923.73	53.27	0.26	Suitable
>93	8.82	0.51	0.52	Highly suitable
Lineament Density				
3.25-4.05	23.03	1.33	0.03	Not suitable
2.44-3.24	183.71	10.59	0.07	Less suitable
1.63-2.43	759.57	43.79	0.13	Moderately suitable
0.812-1.62	480.35	27.69	0.26	Suitable
0-0.811	287.92	16.6	0.50	Highly suitable
Slope				
>40°	27.27	1.57	0.03	Not suitable
30.1-40°	213.6	12.31	0.07	Less Suitable
20.1-30°	481.9	27.78	0.13	Moderately suitable
10.1-20°	507.7	29.44	0.26	Suitable
0-10°	501.1	28.89	0.50	Highly suitable
Soil Texture				
C	1555.65	89.68	0.25	Moderately suitable
CD	178.96	10.32	0.75	Highly suitable
Drainage Density				
0-0.5	970.01	55.92	0.04	Not suitable
0.51-1	375.72	21.66	0.08	Less suitable
1.1-1.5	183.01	10.55	0.11	Moderately suitable
1.6-2	131.31	7.57	0.15	Suitable
>2	74.53	4.30	0.62	Highly suitable
LULC				

Water	8.86	0.51	0.03	Not suitable
Buildup area	419.49	24.17	0.03	Not suitable
Vegetation	212.02	12.22	0.08	Less suitable
Cultivated Land	170.59	9.83	0.13	Moderately suitable
Rangeland	922.73	53.18	0.29	Suitable
Barren Land	1.56	0.09	0.46	Highly suitable
Geology				
MZ	56.02	3.23	0.04	Not suitable
MMRPCCMSR	124.98	7.21	0.04	Less suitable
GCMR	30.26	1.74	0.05	Moderately suitable
PMR	59.23	3.41	0.06	Suitable
KAC	694.5	40.04	0.07	Suitable
UVRVSR	121.88	7.03	0.09	Suitable
CCMUSPC	341.08	19.66	0.12	Highly suitable
CGDGG	162.55	9.37	0.18	Highly suitable
AGAGPM	144.08	8.31	0.35	Highly suitable

Agriculture Water Poverty

Agricultural water poverty is defined as the insufficient availability, access, and management of water resources for agricultural use. AWP has a significant influence on agricultural productivity, food security, and the livelihoods of farmers. Agricultural water poverty has multiple causes that are interrelated and frequently intensified by socioeconomic and environmental factors. Table 3 depicts the Agriculture Water Poverty Index (AWPI) analysis results, showing the area and number of union councils under various AWP classes. Figure 7 illustrates the spatial distribution of AWP across the study area. The analysis suggests that AWP is not evenly distributed over the research area. Out of 35 UCs, only 03 UCs have very low to low AWP (4.61% of the total study area). The majority of UCs 12 reported moderate AWP (39.11% of the total study area), followed by high AWP which was reported from 11 UCs (36.02%). The remaining 9 UCs of the study area are experiencing very high AWP (20.24%). Areas with high or very high AWP are significantly water stressed, with not enough accessible water to meet crop water requirements.

Table 3. District Dir Lower, Area and Number of Union Councils under Various AWPI Classes

S.No.	AWPI Classes	Name of Union Councils	No. of UCs	Percent	Area Km^2	Percent
1	Very Low	Hayaseri, Tormang	2	5.72	69.55	4.01
2	Low	Khungi	1	2.85	10.46	0.60
3	Moderate	Asbanr, Badwan, Bagh Dush Khel, Bishgram, Khadagzai, Khazana, Maskini, Munjai, Noora Khel, Shahi Khel, Tazagram, Timergara	12	34.28	678.50	39.11
4	High	Bandagai, Drangal, Gall, Khal, Kotigram, Khanpur, Mian Kalai, Mayar, Munda, Rabat, Samar Bagh, Zaimdara	11	31.42	624.94	36.02
5	Very High	Balambat, Chakdara, Kambat, Kotkai, Koto, Lajbok, Lal Qilla, Ouch	9	25.71	351.15	20.24
Total		District Dir Lower	35	100.00	1734.61	100.00

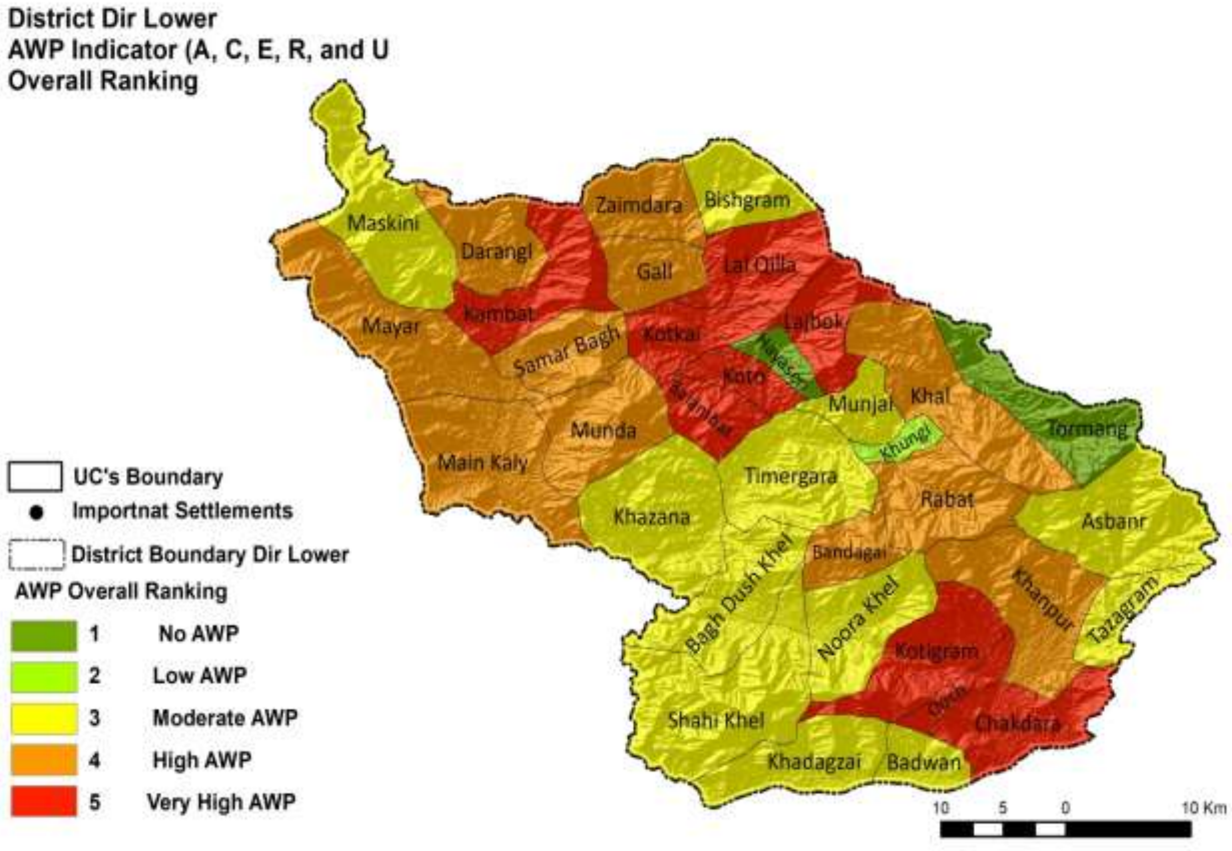


Figure 7 Illustrates the spatial distribution of AWP across the study area.

4. Discussion

4. 1. Final Rainwater Harvesting Suitability Map

Various influence parameters have a significant impact on RWH site selection. According to experts, rainfall is the most essential factor in selecting a RWH site. As a result, the AHP weight assigned to rainfall is 0.31 (30%), followed by runoff potentiality (0.22, 22%). Another essential influencing parameter of RWH is drainage density, which has an AHP weight of 0.21 (21%). LULC with an AHP weight of 0.02 or (2%) is the least suitable factor for RWH. Table 4 displays the respective AHP weights assigned to various influencing parameters based on their efficiency in identifying appropriate RWH sites.

After determining the AHP weight of each major influencing parameter and sub-parameters, a weighted overlay analysis was performed in the ArcMap 10.8 spatial analyst. The study combines all of the influencing parameter layers, including slope, drainage density, geology, soil texture, runoff potential, rainfall potential, land use, land cover, and lineament density. The multi-layer integration of the proposed eight influencing elements yields a suitability map for rainwater harvesting sites over the study area. The RWH site map has been grouped into five suitability classes: not suitable, less suitable, moderately suitable, suitable, and highly suitable. Figure 8 depicts the rainwater harvesting site suitability map.

Table 4. Pair-wise comparison Matrix and Relative Major Parameters AHP Weight for RWH Suitability

Major Parameters	Rainfall	Drainage Density	Runoff	Slope	Soil Texture	Lineament Density	Geology	LULC	Weight
Rainfall	0.29	0.28	0.40	0.35	0.31	0.27	0.25	0.22	0.31
Drainage Density	0.15	0.14	0.27	0.27	0.25	0.23	0.21	0.19	0.21
Runoff	0.29	0.42	0.13	0.18	0.19	0.18	0.18	0.17	0.22
Slope	0.07	0.05	0.07	0.09	0.12	0.14	0.14	0.14	0.1
Soil texture	0.07	0.04	0.04	0.04	0.06	0.09	0.11	0.11	0.07
Lineament Density	0.05	0.03	0.03	0.03	0.03	0.05	0.07	0.08	0.05
Geology	0.04	0.02	0.03	0.02	0.02	0.02	0.04	0.06	0.03
LULC	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02

The RWH site selection analysis identifies a large number of potential rainwater collection sites. Table 5 represents the area covered by various prospective RWH-appropriate sites in the research area, whereas Figure 8 depicts the spatial distribution of various potential RWH sites. Figure 8 depicts the area in % under various RWH prospective sites. The investigation found that sites along the banks of perennial streams and rivers were ideal for rainwater harvesting. This is owing to the strong runoff potential and relatively gentle slope. In contrast, steeper slope locations are typically classed as unsuitable for rainwater harvesting. According to the analysis, 95.58 km^2 (5.51% of the overall study area) is unsuitable for RWH interventions, whereas 905.26 km^2 (52.19%) is less suitable, 539.77 km^2 (31.12%) is moderately suitable, 142.23 km^2 (8.20%) is suitable, and 51.74 km^2 (2.98%) is deemed highly suitable (Table 5, Figure 9).

Though the analysis revealed multiple locations appropriate for RWH intervention, after integrating the Agriculture Water Poverty Index (AWPI) analysis results into the rainwater harvesting sites analysis, at least three prospective dam sites in the study area were selected as the ultimate ARWH sites. These ideal areas were located along the Maidan, Jandool, and River Chakdara.

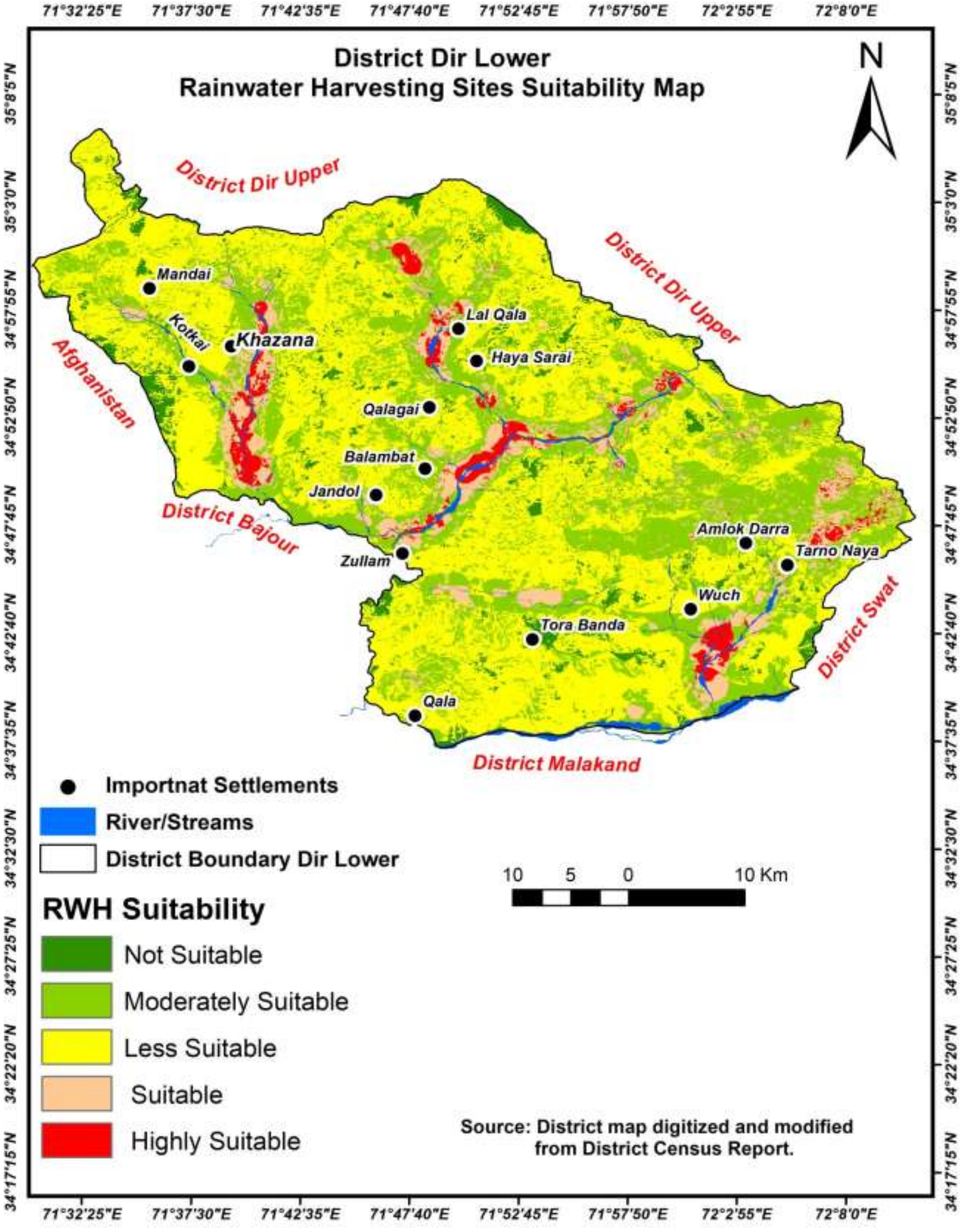


Figure 8. Showing the spatial distribution of numerous prospective RWH sites in the research area.

Table 5. Area under Rainwater Harvesting Suitability (RWHS) Sites

S.No	RWHS Suitability	Area (km^2)	Percentage
1	Not Suitable	95.58	5.51
2	Less Suitable	905.26	52.19
3	Moderately Suitable	539.77	31.12
4	Suitable	142.23	8.20
5	Highly Suitable	51.74	2.98
Total		1734.58	100.00

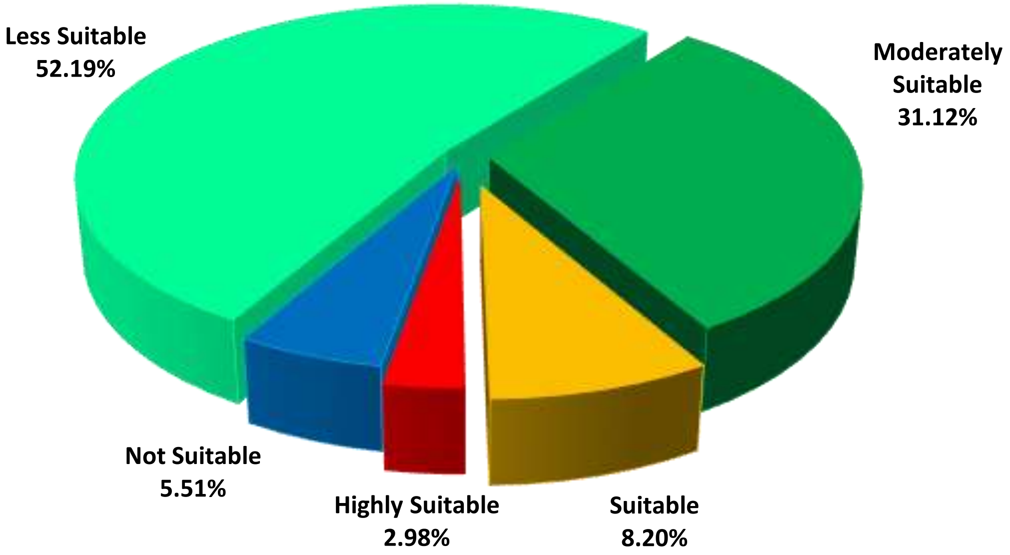


Figure 9. Shows the area in percentage under various RWH potential sites.

Potential ARWH site 1 River Jandool

The potential ARWH site 1 is proposed on the river Jandool in the northeast part of the research region, near the village of Shenzu Qilla. This site catchment includes five UCs with moderate to high AWP (Figure 10B). According to the analysis, the watershed covers 310.86 km^2 and has a slope gradient of 102 m/km. The watershed has rugged topography, with a maximum height of 3237 meters and a minimum height of 757 meters. The overall length of the River Jandool watershed is 18.8 km, with 30 streams of varying orders with a total stream length of 130.06 km. The highest stream is of third-order streams; there are 24 first-order streams with a length of 66.9 km, 05 second-order streams with a length of 33.68 km, and one third-order stream with a length of 19.4 km. Table 6 depicts the water storage capacity of ARWH Site 1 on the Jandool River based on contour analysis, while Figure 10A illustrates the location of the River Jandool watershed.

Table 6. Characteristics of Proposed ARWH Site 1, on River Jandool

Minimum contour	Maximum contour	Embankment height	Maximum width	Minimum width	Length Km	Area km^2	Storage Capacity million m^3
757 m	780 m	23m	1.30 km	0.29 km	1.82	1.19	8.93
757 m	790 m	33m	1.61km	0.17km	3.07	2.20	24.43
757 m	840 m	83m	2.8 km	0.29 km	3.77	4.54	457.68

Potential ARWH site 2 River Maidan

The elevation of the River Maidan watershed ranges from 808 m to 3277 m. The watershed is drained by 23 streams of various orders. Out of 23 streams, 17 are first-order streams, 5 are second-order streams, and one is third-order, with a total length of 94.74 km, supplying a significant amount of water to potential rainwater harvesting sites. The watershed's overall length is 20.67 kilometers, and its maximum breadth is 16.42 kilometers, with a total area of 284.52 km^2. The catchment includes the UCs Gall, Lal Qilla, Kotkai, and Lajbok (all with high AWPI). The ARWH site is intended to deliver agricultural water to UC Balambat and Koto (with exceptionally high AWPI), which are located downstream of the proposed site. With the area's AWPI in mind, an ARWH location near Hayaseri on the River Maidan has been proposed, with three possible dam embankment height-based scenarios. Table 7 displays the characteristics of this ARWH site proposed on River Maidan, while Figure 10B illustrates the location of the River Maidan watershed.

Table 7. Characteristics of Proposed ARWH Site 2, on River Maidan

Minimum contour	Maximum contour	Height of Embankment	Maximum width	Minimum width	Length Km	Area km^2	Storage Capacity million m^3

808 m	848 m	40 m	0.84 km	0.15 km	2.19	1.033	8.70
808m	868m	60 m	1.38km	0.53km	2.95	2.28	15.74
808m	898m	90 m	1.63 km	0.44 km	4.82	4.84	153.7 ^{3}

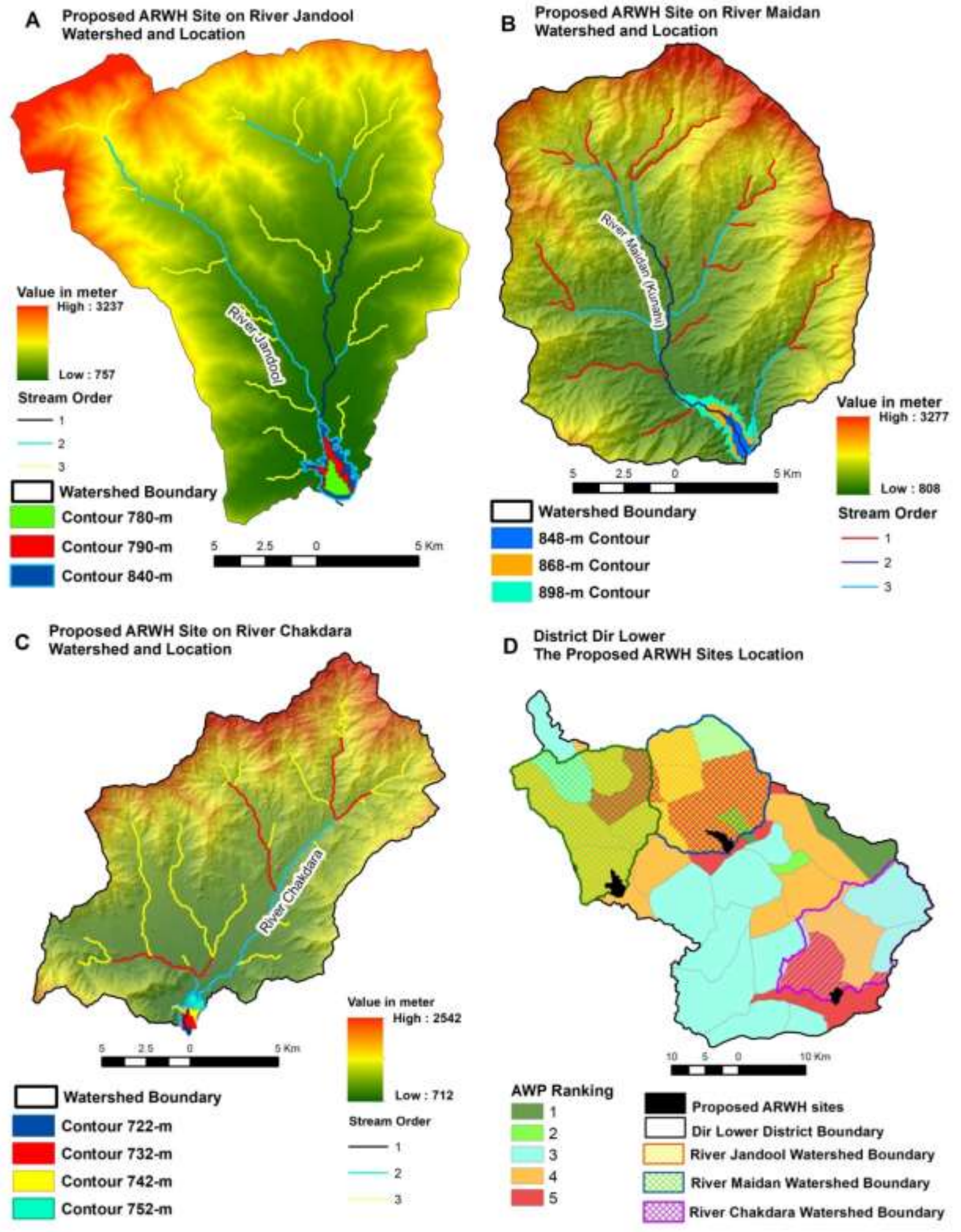


Figure 10 ***(A)*** Illustrates the location of River Jandool watershed and extent of water in the reservoir ***(B)*** Showing the location of River Maidan watershed and the proposed ARWH site ***(C)*** Showing the location of River Chakdara watershed and the proposed ARWH site ***(D)*** Illustrates the map of district Dir Lower (Study area), Showing the location of proposed AWH sites in all

Potential ARWH site 3, River Chakdara

The third rainwater harvesting site is proposed on the River Chakdara. The morphometric examination of the Chakdara stream watershed suggests that the river Chakdara is a fourth-order stream. The watershed is drained by 28 streams of varying orders, including 20 first-order streams, 5 second-order streams, 2 third-order streams, and one fourth-order stream. The watershed has a maximum height of 2542 m and a minimum height of 712 m, with a total length of 21.13 km, a total area of 293.86 km^2, and an 86.6 m/km gradient. The watershed is covered by the UCs of Asbanar and Khanpur, which have moderate and high AWPI, and Kotigram, Ouch, and Chakdara, which have very high AWPI. The proposed site is intended to supply irrigation water to the Kotigram, Ouch, and Chakdara UCs. The site is also proposed to have four alternative dam embankment height possibilities. Table 8 shows the characteristics of the proposed ARWH site on River Chakdara, while Figure 10C illustrates the location of the River Chakdara watershed.

Table 8. Characteristics of Proposed ARWH Site 3, on River Chakdara

Minimum contour	Maximum contour	Embankment Height	Maximum width	Minimum width	Length Km	Area km^2	Storage Capacity million m^3
712 m	722m	10 m	0.19km	0.04km	0.51	0.09	0.29
712m	732m	20 m	0.73km	0.12km	1.32	0.57	3.38
712m	742m	30 m	1.08 km	0.10 km	1.85	1.09	11.39
712m	752m	40 m	1.71km	0.83km	2.36	2.14	28.55

4. Conclusion

The analysis conducted for finding optimal sites for agricultural rainwater harvesting highlights the significance of incorporating a variety of environmental and geographical variables. We can select sites most suited for collecting and storing rainwater by considering LULC, soil texture, drainage density, annual rainfall, slope, runoff potential, and geological factors. According to the study, places with clayey soils, moderate slopes, high drainage density, and large yearly rainfall are optimal for rainwater collection because they have lower infiltration rates, higher water retention capabilities, and high runoff. Furthermore, places with suitable geological formations, such as those with impermeable rock types, contribute greatly to high runoff, hence improving the sustainability of agricultural RWH sites.

The highly suitable ARWH sites cover 51.74 km² (2.98% of the total area) and have ideal conditions for rainwater harvesting, including moderate to high rainfall, high runoff potential, gentle slopes, and favorable soil texture, resulting in low water infiltration and increased water storage. The suitable sites cover 142.23 km² (8.20%), moderately suitable accounts for 539.77 km² (31.12%), less Suitable cover an area of 905.26 km^2 (52.19%), and not suitable cover 95.58 km² (5.51% of the total area). The RWH site selection study identifies a large number of prospective rainwater collection locations within the research region. The integration of the AWPI study with the RWH site selection has resulted in the identification of three significant prospective ARWH dam sites along River Maidan, River Jandool, and River Chakdara. These locations were chosen strategically based on their ability to address water scarcity, increase agricultural output, and promote sustainable water management techniques.

Implementing rainwater harvesting interventions in these suggested regions can boost irrigation water availability, and crop yields, and minimize reliance on external water sources. It also provides a long-term strategy to reduce the effects of water scarcity and climatic variability on agriculture. As a result, the findings of this study are critical for policymakers, farmers, and land planners to make informed choices that promote sustainable agriculture and water management practices.

These findings underscore the importance of geographic and topographic parameters in determining appropriate RWH sites. Water resource management can be considerably improved by focusing on highly suitable locations for RWH implementation, supporting sustainable farming methods, and alleviating water scarcity challenges. This analysis is an important tool for politicians, land planners, and farmers making educated decisions on how to maximize the efficiency and advantages of rainwater harvesting systems.

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