Identification of the Potential Areas/Sites for Rain Water Harvesting and Agriculture Development Using GIS and Remote Sensing in District Dera Ismail Khan (DIK), Pakistan

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Water resources are rapidly depleting in both rural and urban areas of Pakistan due to increasing demands from agriculture and domestic use. This study aims to identify potential rainwater harvesting sites and evaluate the surface runoff potential for sustainable water resource management in the Dera Ismail Khan district of Khyber Pakhtunkhwa province, utilizing GIS and remote sensing (RS) techniques. The research involves both laboratory and field work. Results were validated through a field survey using handheld GPS, while laboratory analysis was performed using ARCGIS software with the Multi-Influencing Factor (MIF) Model. This model incorporates soil classes, slope, geology, and drainage density, analyzed through detailed maps and scales. Geospatial modeling techniques, combined with ground data, led to the identification of several potential rainwater harvesting sites, primarily in the northern and northwestern parts of the district. A total of 26 sites were selected for rainwater harvesting interventions, located on areas ranging from flat to gentle slopes with elevations below 300 meters. The findings of this study can assist the Soil and Water Conservation Department of KP, which is responsible for rainwater harvesting initiatives in the region. The maps produced using the MIF Approach are valuable tools for engineers, planners, and decision-makers in locating and developing dams, storage ponds, and check dams, and for integrating rainwater harvesting into national water policies.

Keywords: GIS, RS, Rainwater, Harvesting, Conservation, ARCGIS, MIFs.

Introduction:

Climate change is characterized by severe and frequent occurrences of floods, droughts, storms, heatwaves, and other extreme weather phenomena, leading to acute water shortages and a significant decline in agricultural productivity [1]. Although agricultural ecosystems are the primary food suppliers globally, they also consume the largest amounts of water [3]. Additionally, water resources are rapidly depleting due to increased industrialization, population growth, urbanization, and irrigated agriculture [1][2]. Consequently, the need to collect, filter, store, and reuse rainfall is becoming increasingly critical.

Rainwater harvesting (RWH) involves the in-situ control, use, storage, and management of rainwater for future efficient utilization [4]. Historically, RWH has been employed in semi-arid and arid regions for both domestic and agricultural purposes [3]. The primary goal of RWH is to act as a supplementary irrigation system by capturing runoff from surrounding areas, storing it, and using it as needed [5].

The failure of monsoons due to climate change has led to uncertain water availability in the Indus Basin [7]. South Asian countries, particularly Pakistan, are expected to face significant water shortages in the coming decades [8]. Pakistan, once a country with surplus water, is gradually becoming water-deficient due to the rapid depletion of freshwater resources. It now ranks third globally among countries facing severe water crises [9]. Northern parts of Pakistan, with higher altitudes and more forest cover, receive more precipitation compared to southern regions such as Balochistan, Sindh, southern KP, and southern Punjab [10]. In these water-scarce areas, agricultural productivity is much lower than in water-rich regions of Pakistan. Therefore, rainwater harvesting is essential in areas where canal irrigation is not feasible to improve agricultural output.

Water scarcity is a significant issue in the southern districts of Khyber Pakhtunkhwa, particularly in District Dera Ismail Khan (D.I. Khan). The lack of water in D.I. Khan results in low agricultural yields despite the availability of extensive cultivable land. This study aims to identify suitable RWH sites and assess the potential for surface runoff to ensure sustainable and efficient irrigation in D.I. Khan using GIS and RS techniques. A key method used in GIS/RS for identifying suitable rainwater harvesting sites is the Multi-Influencing Factor (MIF) Model, which considers soil classes, slope, geology, and drainage density through detailed maps and scales. Effective rainwater management can mitigate flood intensity, frequency, and capture naturally filtered water during dry periods to meet agricultural and domestic needs [2].

The application of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies in identifying potential areas for rainwater harvesting and agricultural development has garnered significant attention in recent years [25]. GIS and RS technologies have revolutionized water resource management by offering tools for precise spatial analysis and monitoring. [23] highlighted that GIS facilitates the creation of detailed topographic and hydrological maps, which are crucial for identifying suitable rainwater harvesting sites. Remote Sensing provides real-time data on land cover, vegetation, and soil moisture, essential for assessing site viability [12]. Despite these advantages, challenges remain, such as access to high-quality and up-to-date satellite imagery, particularly in developing regions. The accuracy of results depends on data resolution and the robustness of analytical models. Researchers like [21] emphasize the need for ongoing advancements in sensor technology and data processing algorithms to address these limitations.

Identifying appropriate sites for RWH is crucial to maximize water availability and enhance land productivity in semi-arid regions [6]. GIS and RS are valuable techniques for analyzing rainfall distribution patterns, drainage patterns, slope, soil properties, floodwater extent, and land resources, especially in remote areas, reducing the need for field-based surveys [1]. These analyses enable the creation of maps showing potential RWH sites [6]. Recent advancements in GIS and RS technologies have improved the accuracy and applicability of these tools in water resource management and agricultural planning. The development of high-resolution satellite sensors and machine learning algorithms for data analysis has enhanced the precision of these tools.

In conclusion, integrating GIS and RS technologies in identifying potential areas for rainwater harvesting and agricultural development is a promising approach offering significant benefits in precision, cost, and time efficiency. However, the effectiveness of these technologies depends on data quality and the sophistication of analytical methods. Continued research and technological advancements are essential to overcome current limitations and fully realize the potential of GIS and RS in sustainable resource management.

Several studies have utilized GIS and RS to identify optimal sites for rainwater harvesting. [16] identified potential groundwater zones in Mirzapur district, UP, India, using a weighted overlay analysis combined with the Analytical Hierarchy Process (AHP) method. Their study classified the groundwater potential map into four categories: excellent (24.4%, 1101 km²), good (40.07%, 1840 km²), moderate (29.8%, 1347 km²), and poor (5.1%, 228 km²). [10] used GIS and multi-criteria decision analysis (MCDA) to identify potential RWH sites in Mashhad Plain Basin, Iran, integrating the SWAT model. Another study by [22] employed machine learning techniques to enhance soil moisture estimation from RS data, improving site suitability analyses.

In agricultural development, GIS and RS are invaluable for site suitability analysis. [20] demonstrated these technologies to identify areas with favorable soil conditions, appropriate slope, and adequate water availability in India, using a multi-criteria decision-making approach. [24] integrated RS data with GIS to map rainwater harvesting sites in Ethiopia, emphasizing the role of soil type and land use in the assessment.

In Pakistan, several studies have focused on identifying RWH sites using RS and GIS. [15] analyzed runoff patterns and identified potential RWH sites in the Potohar Plateau region using GIS, HEC-GeoHMS, HEC-HMS, and Remote Sensing. [9] used an integrated approach to find potential RWH locations in Kohat District, while [8] identified suitable RWH sites in Ghazi Tehsil, District Haripur, using GIS and RS technologies.

Materials and Methods:

This study aims to identify suitable sites for rainwater harvesting (RWH) in District D.I. Khan using remote sensing (RS) and GIS technologies. The research variables include rainfall, elevation, geology, slope, drainage density, land use and land cover, soil, and lineament. This study combines both laboratory and field work. Field results were verified with hand-held GPS surveys, while laboratory analysis was conducted using ARCGIS software and other geospatial tools.

The Study Area:

District Dera Ismail Khan (D.I. Khan) is located in the Khyber Pakhtunkhwa Province of Pakistan, within the Dera Ismail Khan Division. The district spans latitudes 31°15' to 32°32' N and longitudes 70°11' to 71°20' E (see Figure 2). Positioned approximately 300 kilometers south of Peshawar, the provincial capital, D.I. Khan is situated on the western bank of the River Indus (see Figure 2). The town of Dera Ismail Khan serves as the district's capital. Covering an area of 9,334 km², the district has a population of 1,693,594 and is subdivided into five tehsils: Dera Ismail Khan, Daraban, Kulachi, Paharpur, and Paroa.

D.I. Khan is in a subtropical arid zone with mild winters and hot summers. The mean annual temperature is 24°C, with average maximum and minimum temperatures of 32°C and 17°C, respectively. The region receives an average annual rainfall of 9 inches, with potential evapotranspiration rates being eight to nine times higher than the annual rainfall. Rainfall is infrequent but can be intense, occasionally causing floods. The district's mountainous areas are composed of rocks from the Paleozoic to early or middle Pleistocene age, while the plains consist of unconsolidated rocks from the middle Pleistocene to Holocene (Recent) age, primarily alluvium deposited by the River Indus and piedmont deposits from the northern and western hills.

Agriculture is the main source of income for the district's residents, though only a small portion of cultivable land is currently utilized. Of the total 730,575 hectares of cultivable land, only 233,100 hectares are under cultivation. The irrigated area totals 119,915 hectares, including 104,080 hectares by canal, 15,546 hectares by tube wells, and 289 hectares by other sources. Major crops include cotton, rice, maize, gram, sugar cane, barley, wheat, and mustard. Rain-fed cultivation of wheat and gram predominates, with some vegetables and fodder also grown under irrigation.

Data Collection:

For this study, a 30 m resolution SRTM DEM was used to extract data on drainage density and drainage networks (Table 1 & Figure 1). Stream networks were derived using the hydrology tool, and drainage density was calculated from these networks. The ARC GIS Spatial Analyst tool was employed to prepare elevation data from the 30 m resolution SRTM DEM. A slope map was also created from the DEM using ARCGIS Spatial Analyst. Rainfall data from 12 climate stations within and around the study area (Table 1) was obtained from the Pakistan Meteorological Department (PMD), Islamabad. This historical data, spanning forty years (1981-2020), was imported into ARCGIS and spatially interpolated to generate a rainfall map. The geological map was extracted from northern Pakistan maps originally created by M. Asif Khan and M.P. Searle, and then reclassified into various rock types.

The land use and land cover layer was derived from Landsat 8 (2019) imagery with a 30 m resolution, using supervised classification methods in ARCGIS 10.5. Lineament data was generated from Landsat 8 pan-sharpened reflective bands, with PCI Geomatical 2017 software used for extraction. Lineament density was calculated using the density analysis tool in ARCGIS 10.5. The soil map was sourced from the Soil Survey of Pakistan, with soil types and groundwater recharge properties determined through a literature review.

Table 1: Data sources

S.NO	Data Type	Department/Source
1	Rainfall data	Meteorological Station
2	Soil data	Soil survey of Pakistan
3	Geology data	Soil survey of Pakistan
4	Lineament data	Landsat 8 Image
5	Landsat Image	USGS
6	DEM Model	USGS
7	Topo sheets	Survey of Pakistan

Data Analysis:

First, parameters relevant to rainwater harvesting (RWH) techniques were identified through a literature review. These parameters included soil, drainage density, geology, slope, lineament, rainfall, and land use and land cover. Next, these parameters were preprocessed to assign scores and weights, ensuring uniformity. Each parameter in the thematic layers was ranked, and weights were assigned based on their level of influence—major, minor, or no influence. The impacts of all major and minor factors were then calculated using the following equation:

$$EQ: [X+Y \div \Sigma (X+Y)] \times 100$$

Where X denotes the major effect of factors, and Y indicates the minor effect. The thematic layers for all parameters were then integrated with their scores using the spatial analysis extension in ArcMap 10.5 software. In the fifth step, the output layers were categorized into three zones—High Suitable, Moderate Suitable, and Least Suitable—for rainwater storage using a reclassification technique. The sixth and final step involved generating final maps to display suitable sites for check dams, mini dams, terracing, and other conservation measures, and analyzing the suitability of these proposed sites.

Results and Discussion:

Land Use/Land Cover Map:

Land use and land cover patterns (Table 2 & Figure 3) were developed for the study area using Landsat 8 satellite data, complemented by a ground-truthing survey. Five land use classes were considered: built-up land, vegetation, water bodies, barren land, and agricultural land. The land use classes and the area covered by each class are detailed in Table 2.

Table 2: The Land use of D.I. Khan

Land Use	Area in Sq.km	Data Used
Vegetation	18909.8307	Landsat 8
Built Up land	2036.6208	Landsat 8
Barren Land	8275.1823	Landsat 8
Water Body	254.7729	Landsat 8

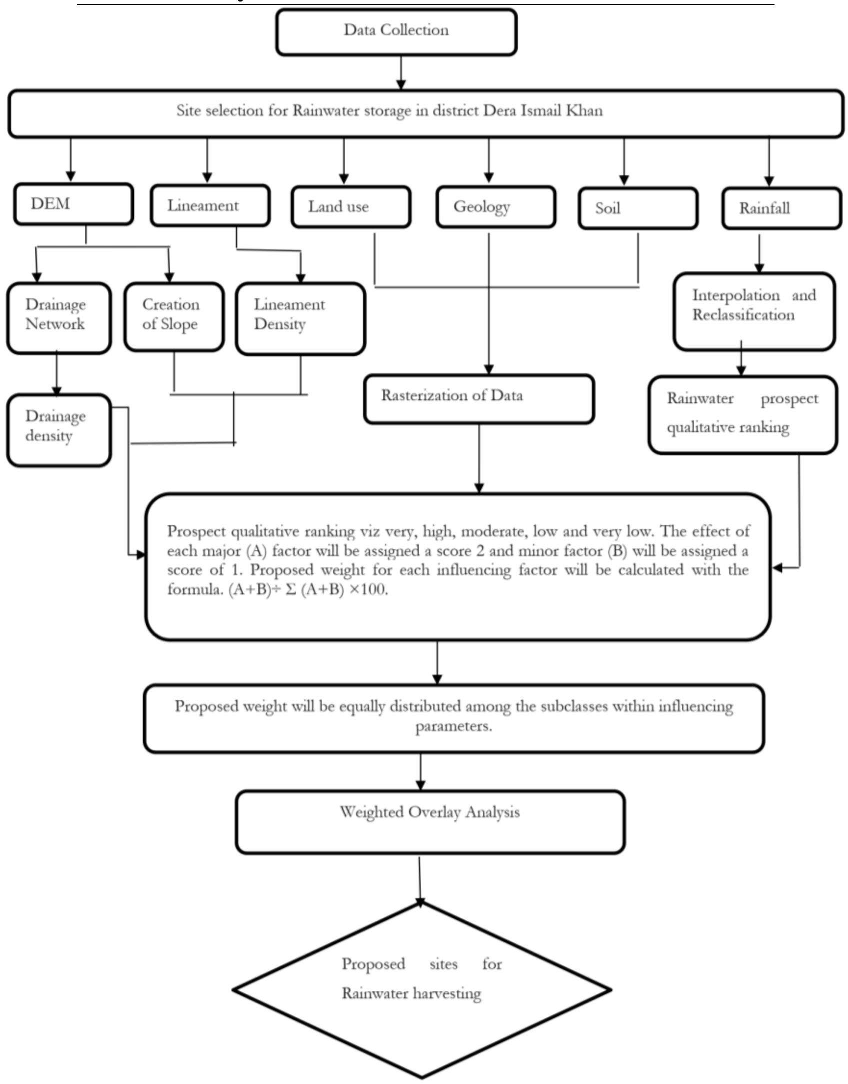

Figure 1: Flowchart showing the research methodology of the study

Slope:

Slope is measured in degrees, ranging from 0° to 89°. It significantly impacts runoff generation and water flow velocity in an area [16]. Gentler slopes enhance the efficiency of water storage for harvesting. The slope map was developed in ArcGIS using SRTM DEM with a spatial resolution of 30m [17]. Figure 4 illustrates that the study area's slope varies from very gentle to gentle. According to IMSD guidelines, the slope of D.I. Khan has been categorized into four classes: 0-23.18°, 23.18-40.38°, 40.38-55.49°, 55.49-73.05°, and 73.05-89.56°. These classifications were calculated using ArcGIS, with values in degrees (see Figure 4).

Lineament Density:

Lineaments are indicators of subsurface faults and fractures that affect groundwater availability, including reservoirs and canals. They are typically found in permeable zones, and lineament density is often related to groundwater potential [18]. Using ArcGIS 10.5, the density analysis tool calculated the lineament density of the study area. District D.I. Khan was classified into four categories: very low (0-0.37), low (0.37-0.74), moderate (0.74-1.11), and high (1.11-1.48). Areas with high lineament density were deemed least suitable for rainwater harvesting, while low-density zones were assigned higher weightage and categorized as high potential zones. The lineament map is shown in Figure 5.

Drainage Density:

To develop the slope, drainage, and elevation maps of the study area, a 30m spatial resolution SRTM digital elevation model (DEM) was utilized. ArcGIS 10.5 provides specialized tools for slope and elevation analysis. Drainage density indicates the level of infiltration and surface water runoff in an area. The study area was classified into drainage density regions: very low (0-42.56), low (42.56-85.12), moderate (85.12-132.40), and high (132.40-241.17) (Figure 6). Figure 6 depicts various drainage density zones, where low drainage density corresponds to lower runoff and infiltration, and vice versa. Zones with low to moderate drainage density were given higher weightage values and considered most suitable for rainwater harvesting.

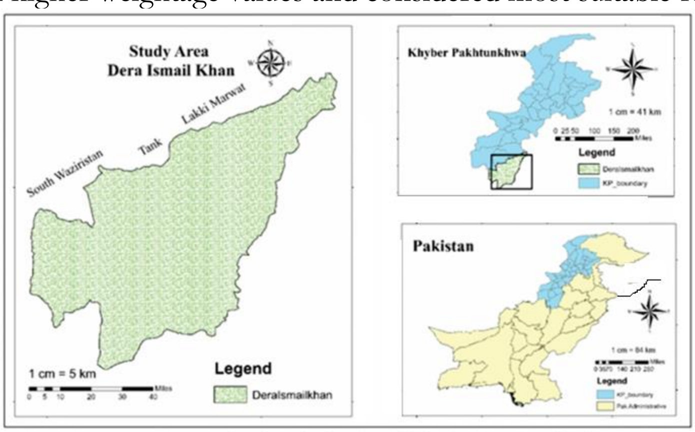

Figure 1:Map showing the location of District Dera Ismail Khan

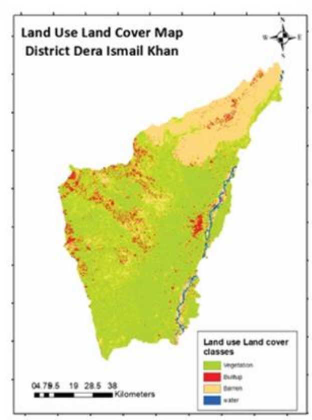

Figure 2:Land use Land cover of D.I Khan

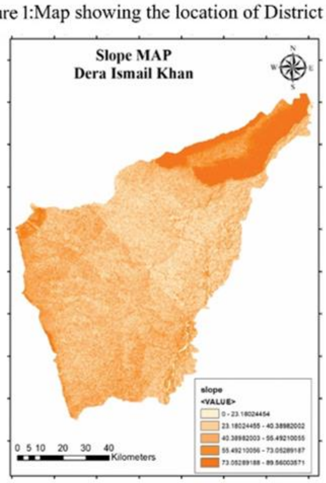

Figure 3:Slope map of D. I. Khan

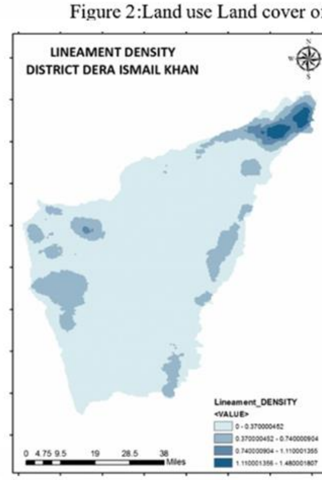

Figure 4:Lineament Map of the study area

Soil:

The study area features a range of soil types, including heterogeneous patches, loamy and clayey saline soils, loamy and clayey soils, and loamy sandy stratified sands of river plains.

Loams, composed of sand, clay, and silt, are fertile, well-drained, and easily tilled. Sandy soils, with the largest particles, have limited moisture absorption but excellent aeration, facilitating oxygen uptake by plant roots. Weights were assigned based on soil composition and water-holding capacity. Loamy soils were given a lower weight due to their high porosity and permeability (Figure 7).

Geology:

Geology significantly affects water occurrence and distribution. The study area includes sedimentary and metamorphic rocks. Predominant geological formations are piedmont deposits, Eocene sedimentary rocks, Pliocene and Miocene sedimentary rocks, alluvium, and extrusive mud from Jurassic and Triassic sedimentary rocks. Different rock types influence soil storage capacity; some allow water to percolate and recharge underground reserves, while others resist percolation. Metamorphic rocks, with low percolation rates, were assigned a higher weight, whereas sedimentary rocks, with more sand and lower percolation rates, received a lower weight (Figure 8).

Rainfall Map:

Rainfall, a critical factor for water recharge, was analyzed in this study. The study area was divided into five zones with equal intervals, and weights were assigned to each zone accordingly. Rainfall data from 1970-2018, obtained from the regional meteorological office in Peshawar, was spatially interpolated using ArcMap 10.5. This data was reclassified into five classes: 422-449 mm, 449-466 mm, 466-481 mm, 481-505 mm, and 505-534 mm (Figure 9). Areas with higher rainfall were assigned higher weights due to their greater potential for aquifer recharge and fresh water supply.

Discussion:

After data collection, thematic layers were converted into raster format for weighted overlay analysis using ArcGIS spatial analyst tools. The data was transformed from vector to raster format, and ranks and weights were assigned to each factor and its subclasses. Overlay analysis was conducted using the 'weighted overlay' tool in ArcGIS, which combines multiple raster layers with a common measurement scale, weighting each layer according to its importance. This analysis produced an output layer with values ranging from 1 to 2, where 1 indicates very poorly suitable potential zones and 2 indicates very good rainwater potential zones. Weights were assigned to each parameter out of 100, as shown in Table 4. Table 3 presents the relative rates of each factor, calculated by the cumulative sum of major and minor effects, and the proposed scores for each influencing factor using the formula from Magesh (2012).

$$EQ: [X+Y \div \Sigma(X+Y)] \times 100$$

Where X signifies a factors major effect and Y represents a factors minor effect.

Table 3: Major and Minor Influence of Parameters

Select Parameter	Major Effect (A) Higher	Minor Effect (B) Low	Relative Effect of Each Parameter(A+B)	Proposed Weight of Each including Parameter
Topography	2+2	1+1	6	15
Drainage Density	2+2	1+1	6	15
Geology	2	1	3	5
Soil Type	2	1+1	4	10
Land Use Land Cover	2+2+2	1+1	8	20
Lineament Density	2+2	1+1	6	15
Rainfall	2+2+2	1	7	20
			Σ 40	Σ 100

Table 4: Thematic Layers

Select Parameter	Subclasses within influencing Parameters	(Qualitative Rank)	Weight of respectively influencing layer	Rainwater Prospects (Quantitative Rank)
Rainfall in mm	422-449 449-466 466-481 481-505 505-534	Very Low Low Moderate High Very High	20	8 6 4 2 1
Slope in degree	0 -23.18 76.91 - 40.38 40.38 – 55.49 55.49-73.05 73.05-89.56	Very Low Low Moderate High Very High	15	1 5 7 2 3
Drainage density in km/sq km	0-42.56 42.56-85.12 85.12-132.40 132.40-241.17	High Moderate Low Very low	15	7 5 2 1
Geology	Sedimentary Metamorphic	Low High	5	2 3
Land Use Land Cover	Vegetation Built Up Barren land Water bodies	Very high High Moderate Low	20	8 6 4 1
Lineament density in km/sq km	0-0.16 0.16-0.41 0.41- 0.75 0.75-1.66	High Moderate Low Very low	15	7 5 2 1
Soil	Patchy Cover Soil Loamy and Clayey Soil Loamy Sandy Stratified Sand of River Plains	Very low Moderate Low	10	2 3 5

Existing literature was consulted to assign weights and ranks to each thematic layer and its individual classes. Weights ranged from 1 to 13, with 13 indicating the most suitable locations for rainwater harvesting (RWH) and 1 representing the least suitable sites. Each thematic layer was classified into varying numbers of classes: the land use and land cover layer were divided into four classes, the drainage layer into four classes, and the geology layer into five classes (Table 4). To perform the weighted overlay analysis, all rasters were converted to the WGS_1984_UTM_Zone_43 projected coordinate system to ensure uniformity. Table 5 and Figure 10 present the details of the final identified suitable sites for RWH as determined in this study.

Table 5: Areas covered by suitable RWH sites identified in this study

Potential Zones	Area Km^2
Poor	3251.8116
Moderate Suitable	14758.5276
Suitable	9211.734
Most suitable	1348.3152

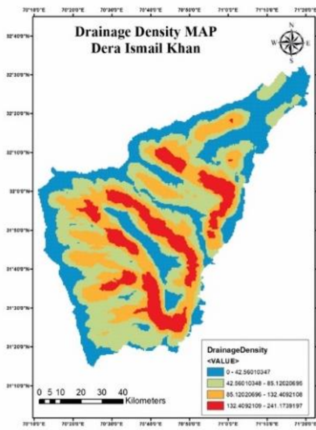

Figure 5:Drainage Density of the study area

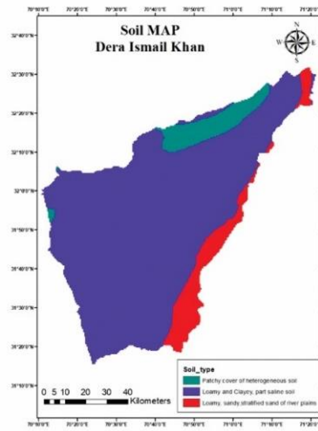

Figure 6:Soil map of the study area

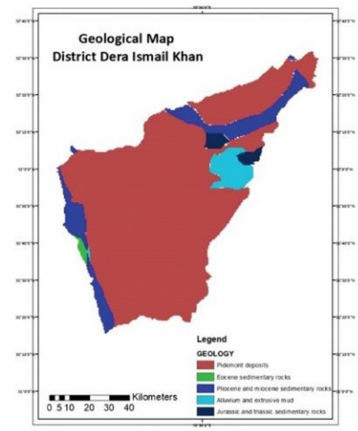

Figure 7:Geology map of D.I. Khan

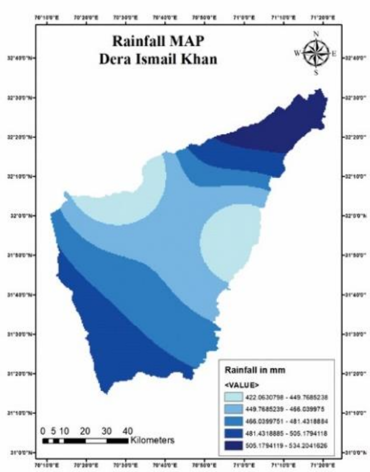

Figure 8:Rainfall map of the study area

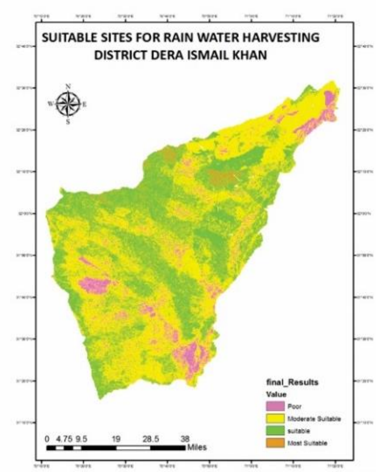

Figure 9:Final map showing the Potential RWH sites in D.I. Khan District

Conclusion:

The findings of this study are highly valuable for the efficient management of rainwater harvesting (RWH) in D.I. Khan and other areas of Pakistan. The integrated application of GIS, Multi Influencing Factor (MIF) techniques, and remote sensing has proven to be an efficient, time-saving, and cost-effective method for identifying optimal RWH zones. This approach facilitates quick decision-making for sustainable water resource management. GPS data, topographic maps, and satellite imagery were utilized to develop thematic layers, including lineament density, geology, slope, soil, drainage density, rainfall, and land use. These layers were assigned appropriate weights using the MIF technique and subsequently integrated within the GIS environment to create maps showing potential RWH sites in the D.I. Khan district. The study area was categorized into four zones: 'high', 'moderate', 'good', and 'poor', based on the potential RWH zone map.

The results of this study are also beneficial for the Soil and Water Conservation Department, which oversees rainwater harvesting initiatives. The maps generated using the MIF approach will aid planners, engineers, and decision-makers in identifying ideal sites for dams, check dams, and other structures for soil and water conservation in the study area. This study demonstrates that the integrated use of GIS and remote sensing techniques can be applied to identify suitable RWH sites in other regions of Pakistan and beyond. With available data on parameters such as geomorphology, dykes maps, surface and subsurface lineaments, hydrogeology, lithology, aquifer resistivity, topography, and surface water bodies, this approach can be adapted for RWH site identification in various locations. Future research should continue to explore RWH potential and identify suitable sites in light of current and anticipated water shortages due to climate change and related challenges.

Disclaimer:

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References:

[1] Farooq, S., Kausar, R., Ashraf, A., & Haider, B. (2020). Exploring Surface Runoff Potential and Water Harvesting Sites in Dera Ismail Khan Rod-kohi Area Using GIS and Remote Sensing: Assessment of Runoff Water Harvesting Potential Using Geo-Spatial Techniques. Proceedings of the Pakistan Academy of Sciences: A. Physical and Computational Sciences, 57(2), 1-10.

[2] Buraihi, F. H., & Shariff, A. R. M. (2015). Selection of rainwater harvesting sites by using remote sensing and GIS techniques: a case study of Kirkuk, Iraq. Jurnal Teknologi, 76(15).

[3] Mahmoud, S. H., & Alazba, A. A. (2015). The potential of in situ rainwater harvesting in arid regions: developing a methodology to identify suitable areas using GIS-based decision support system. Arabian Journal of Geosciences, 8, 5167-5179.

[4] Velasco-Muñoz, J. F., Aznar-Sánchez, J. A., Batlles-delaFuente, A., & Fidelibus, M. D. (2019). Rainwater harvesting for agricultural irrigation: An analysis of global research. Water, 11(7), 1320.

[5] Yazar, A., & Ali, A. (2016). Water harvesting in dry environments. Innovations in dryland agriculture, 49-98.

[6] Tumbo, S. D., Mbilinyi, B. P., Mahoo, H. F., & Mkilamwinyi, F. O. (2013). Identification of suitable indices for identification of potential sites for rainwater harvesting. Tanzania Journal of Agricultural Sciences, 12(2).

[7] Hussain, S., Malik, S., Masud Cheema, M., Ashraf, M. U., Waqas, M., Iqbal, M., ... & Afzal, H. (2020). An overview on emerging water scarcity challenge in Pakistan, its consumption, causes, impacts and remedial measures. Big Data in Water Resources Engineering (BDWRE), 1(1), 22-31.

[8] Khan, M. D., & Khattak, M. (2012). Siting of rainwater harvesting locations in District Haripur using Geographic Information Techniques. Journal of Himalayan Earth Science, 45(2).

[9] Mahmood, K., Qaiser, A., Farooq, S., & Nisa, M. U. (2020). RS-and GIS-based modeling for optimum site selection in rain water harvesting system: an SCS-CN approach. Acta Geophysica, 68, 1175-1185.

[10] Sarfaraz, S. A. R. D. A. R., Arsalan, M. H., & Fatima, H. I. R. A. (2014). Regionalizing the climate of Pakistan using Köppen classification system. Pakistan geographical review, 69(2), 111-132.
[11] Doulabian, S., Ghasemi Tousi, E., Aghlmand, R., Alizadeh, B., Ghaderi Bafti, A., & Abbasi, A. (2021). Evaluation of integrating swat model into a multi-criteria decision analysis towards reliable rainwater harvesting systems. Water, 13(14), 1935.
[12] Khanal, S., Kc, K., Fulton, J. P., Shearer, S., & Ozkan, E. (2020). Remote sensing in agriculture—accomplishments, limitations, and opportunities. Remote Sensing, 12(22), 3783.
[13] Adham, A., Sayl, K. N., Abed, R., Abdeladhim, M. A., Wesseling, J. G., Riksen, M., ... & Ritsema, C. J. (2018). A GIS-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq. International Soil and Water Conservation Research, 6(4), 297-304.
[14] Singh, L. K., Jha, M. K., & Chowdary, V. M. (2017). Multi-criteria analysis and GIS modeling for identifying prospective water harvesting and artificial recharge sites for sustainable water supply. Journal of cleaner production, 142, 1436-1456.
[15] Mahmoud, S. H., & Tang, X. (2015). Monitoring prospective sites for rainwater harvesting and stormwater management in the United Kingdom using a GIS-based decision support system. Environmental Earth Sciences, 73, 8621-8638.
[16] Patel, A. K., Sharma, M., Singh, A., Dubey, S., Chandola, V. K., & Mishra, S. (2024). Groundwater Potential Zones Using Multi–Criteria Decision Making for Mirzapur, District, UP, India. International Journal of Environment and Climate Change, 14(4), 27-45.
[17] Ghani, M. W., Arshad, M., Shabbir, A., Mehmood, N., & Ahmad, I. (2013). Investigation of potential water harvesting sites at Potohar using modeling approach. Pakistan Journal of Agricultural Sciences, 50(4).
[18] Tiwari, K., Goyal, R., & Sarkar, A. (2018). GIS-based methodology for identification of suitable locations for rainwater harvesting structures. Water resources management, 32, 1811-1825.
[19] Mbilinyi, B. P., Tumbo, S. D., Mahoo, H., & Mkiramwinyi, F. O. (2007). GIS-based decision support system for identifying potential sites for rainwater harvesting. Physics and Chemistry of the Earth, Parts a/b/c, 32(15-18), 1074-1081.
[20] Anchan, S. S., & Prasad, H. S. (2021). Feasibility of roof top rainwater harvesting potential-A case study of South Indian University. Cleaner Engineering and Technology, 4, 100206.
[21] Chen, Y., Samuelson, H. W., & Tong, Z. (2016). Integrated design workflow and a new tool for urban rainwater management. Journal of environmental management, 180, 45-51.
[22] Zhang, X., Xia, S., Ye, Y., & Wang, H. (2021). Opportunistic pathogens exhibit distinct growth dynamics in rainwater and tap water storage systems. Water Research, 204, 117581.
[23] Han, Y., Xu, H., Bi, X., Lin, F., Jiao, L., Zhang, Y., & Feng, Y. (2019). The effect of atmospheric particulates on the rainwater chemistry in the Yangtze River Delta,

China. Journal of the Air & Waste Management Association, 69(12), 1452-1466.
[24] Haile, G., & Suryabhagavan, K. V. (2019). GIS-based approach for identification of potential rainwater harvesting sites in Arsi Zone, Central Ethiopia. Modeling Earth Systems and Environment, 5, 353-367.
[25] Wandera, M. (2017). Sustainable Rain-Water Harvesting Strategies. Proceedings of the Sustainable Research and Innovation Conference.