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GIS BASED DELINEATION OF GROUNDWATER POTENTIAL FOR AGRICULTURAL PRODUCTION ZONES IN DERA ISMAIL KHAN, PAKISTAN

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ABSTRACT: With fast population growth coupled with climbing irrigation demands have resulted in an alarming scarcity of surface water. Because it can be challenging to locate surface water that meets the needs of both home and agricultural uses, there is an increased need for groundwater. Because it has been difficult to find surface water resources that can satisfy household and agricultural needs, groundwater dependence has increased. Thus, this study endeavored to classify potential groundwater zones in district Dera Ismail Khan, Khyber Pakhtunkhwa by leveraging a holistic approach comprising remote sensing, geographic information systems (GIS), and multi influencing factors (MIF). The delineation of groundwater recharge considered various aspects such as precipitation, geology, land use and cover, slope gradients, soil classifications, drainage density, and lineament density. The MIF system was employed to ascertain the relative significance of each contributing factor. Following this, all thematic strata were integrated using the relative weights derived from MIF through a weighted overlay analysis conducted in a GIS environment to map potential groundwater regions. For the purpose of model validation and verification, 30 observed tube wells and bore well were marked and their depth were identified. This research identified that groundwater recharge areas comprised high (19.29%), moderate (61.18%), low (16.45%), and very low (3.06%) potential regions. The validation analysis exhibited a remarkable 90% concurrence between the groundwater inventory data and the designated potential groundwater zones. Consequently, these reliable findings aid decision-makers and water users in the sustainable exploitation of groundwater resources within the area under investigation as an alternative for developing agriculture and fulfilling domestic use.

Key Words: population growth, potential groundwater zones, drainage density, GIS environment

Introduction

Groundwater resources have a major influence on a country's social and economic development and are essential to the global water cycle. (Li et al., 2023). Precise information regarding fluctuations in groundwater is essential for effective water resource management and for advancing environmental and disaster-related research. Thus, monitoring groundwater changes is essential to promoting social and economic progress. (Zhong et al., 2009). Water has become more and more in demand in recent years due to the rapid growth of industry, agriculture, and household activities. Since groundwater has a wider spread and lower levels of contamination, it is mostly used to meet this need. (Arkoprovo B et al., 2012). Terrestrial water storage (TWS) encompasses the sum total of water stored within groundwater storage (GWS), soil, rivers, lakes, dams, snow, and vegetation. TWS is a critical component of land-atmosphere interactions and the total hydrological cycle (Rodell et al., 2018). Fluctuations in TWS significantly influence water flux interactions among diverse earth system factors by indicating regional water equilibrium or disequilibrium (Abhishek et al., 2021), ice sheet and glacier mass variations (van den Broeke et al., 2009), natural hazards like floods and droughts (Abhishek & Kinouchi, 2021) , and sea-level rise (Pokhrel et al., 2012) .

Currently, there is not enough surface water available to meet the needs of all industries, including industrialization, agriculture, irrigation, and drinking. The need for groundwater has increased as a result of this fact. The rising use and scarcity of surface water are caused by a number of factors, such as high population density, unequal distribution of water resources, spatial and temporal restrictions, commercial growth, and climate change. Ali el al 2024b, Kaliraj et al., 2014; Krishnamurthy et al., 1996; Murthy, 2000; Selvam et al., 2014a). The presence of groundwater in particular places is not accidental; rather, it results from a confluence of elements including geological, hydrological, physiographical, and biological interactions. Thus, for effective groundwater management, planning, and exploitation, groundwater of low quality must be mapped to identify groundwater quality zones. Thus, the purpose of this study is to compare and define the quality of groundwater and how it affects the study's agricultural economy.

MATERIALS AND MATERIAL

The study area Dera Ismail Khan is the southernmost district of Khyber Pakhtunkhwa. In the study area the majorly rural population depend on Agriculture. The district has total geographical area of 9,33,410 Ha (9334 sq.km) in which 7,30,577 Ha (7305.75 sq.km) is total reported area out of which 2,17,841 Ha (2178 sq.km) is total cultivated area in which only 1,05,144 Ha (1051.45 sq.km) is net sown while 1,12,698 Ha (1126.97 sq.km) is current fallow and 3,32,765 Ha (3327.66 sq.km) is culturable wasteland (as per the annual land use of Crop Reporting Services Khyber

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Pakhtunkhwa). Due to the low rainfall in the area, people are suffering greatly from the lack of clean drinking water for domestic and agricultural uses. In the CRBC Command Area of the district majorly Maize, rice, sugarcane and cotton crop in kharif season are cultivated, while rest of the district agriculture land is un-irrigated completely dependent on rainwater while those irrigated land still faces problem due to shortage of water.as after the recent flood 2022 and no rainfall in the kharif season ,the surface water level CRBC is low that it affected the Rabi Season of 2023 and the cultivation of Rabi Crop(Wheat) is also affected(as per the report of Crop Reporting Services Khyber Pakhtunkhwa).Therefore an effective solution is required to fulfil the water need particularly for agriculture and domestic use. This main aim of this study is to identify the potential zones of groundwater using Multi-Criteria Decision Making (MCDM) approaches, Multi Influencing Factor Analysis (MIF) with the help of Geographic Information system and Remote sensing. The major variables of this study consist of Soil, Land use, Geology, Lineament, Precipitation, Drainage Density, Slope, which are prerequisite for groundwater potentiality identification

The study area, consist of five exclusive regions, exhibits an array of diverse physiographic features, including Piedmont Plains, Mountain Highlands, Aeolian Deposits, Floodplains and Gravel Fans, providing a captivating and professionally diverse landscape for study. Situated in the basin's flood plains, the Dera Ismail Khan district experience a special physical location.

Study Area

Dera Ismail Khan, lie at an average height of 186 m from mean sea level. The study area lies from 31° 36' 51" to 31° 57' 50" north latitudes and 70° 40' 22" to 70° 57' 52" east longitudes. The total area of the study area is 9,334 sq.km and is located within the Lower Indus Basin. With a population of 1,627,132 individuals as of the 2017 Census, the region abides by the census boundary. The districts of Bhakkar and Dera Ghazi Khan in Punjab border the district on the east. To the southwest, the formidable Takht-e-Sulaiman Mountain in Baluchistan province and Dera Ismail Khan are separated by a narrow swath of the South Waziristan area, which was formerly a part of the Federally Administered Tribal Areas. The Tank District is to the northwest (Figure 1).

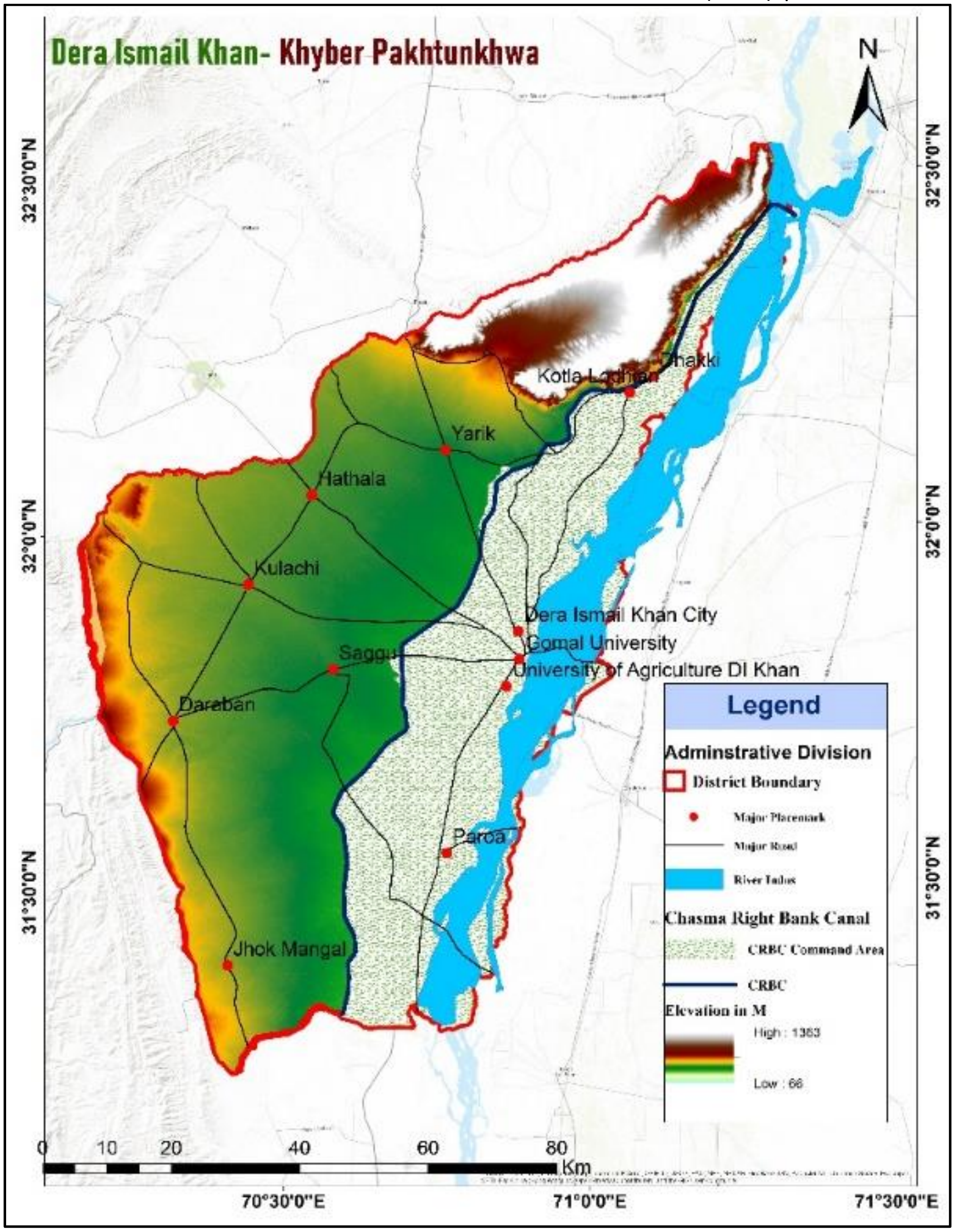

Figure 1: Location map of the study area

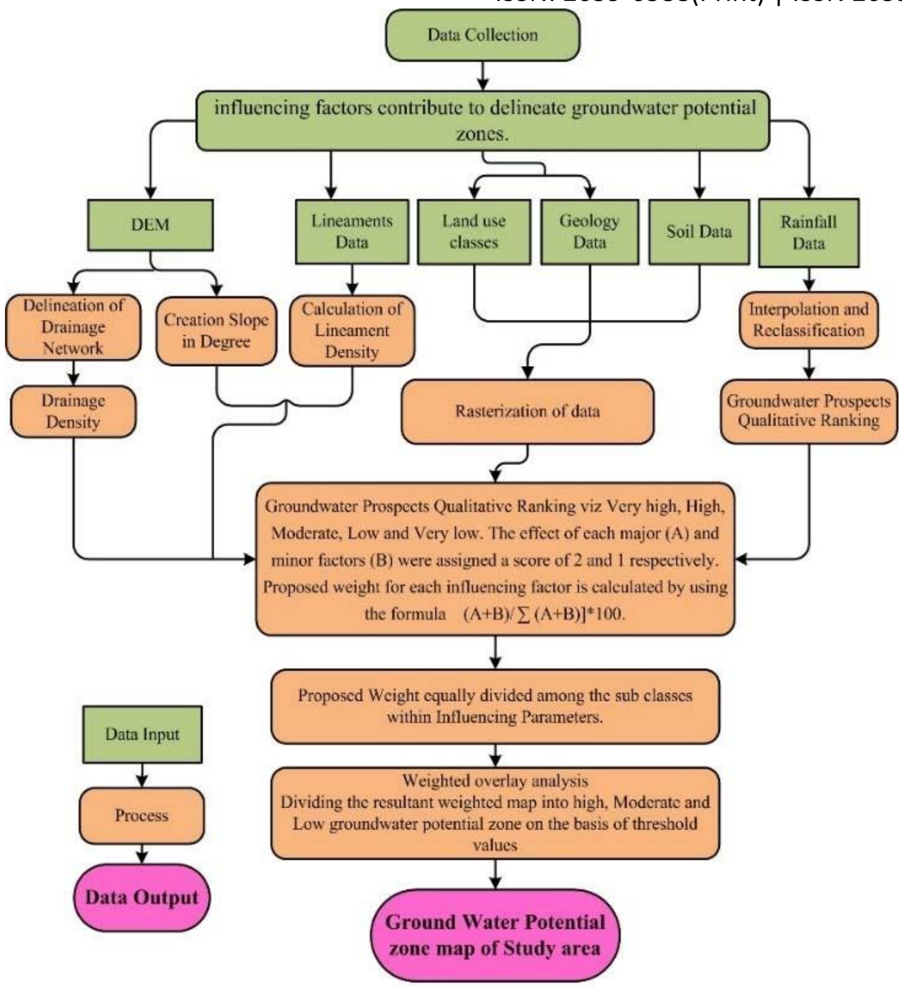

Figure 2: Research Methodology

Data Acquisition. Both primary and secondary date were used in this study. Global Positioning system was used in field survey to find out the coordinates of Agriculture, built up, barren land and Tube well/ Borewells. The secondary data like Soil, LULC, Liniment Density, Slope, Geology, Drainage Density, Rainfall of the study area were gathered and was exported to ArcGIS Platform (Figure 2).

RESULT AND DISCUSSION

Drainage density. By using Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) having 30 m spatial resolution the drainage and elevation of the study area are evaluated.

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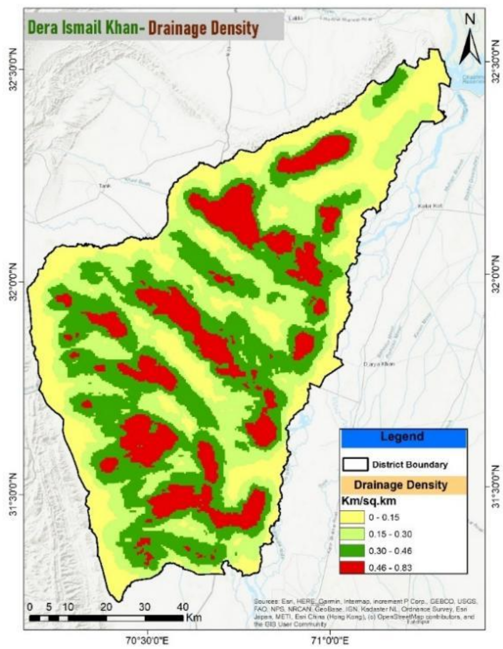
ArcGIS 10.8 provides advanced features for slope and elevation evaluation. Drainage density illustrates water runoff and groundwater infiltration in a given area, with classifications ranging from very low (0-0.15) to high (0.46-0.83). Drainage density zones are depicted on the map accordingly. Areas with poor drainage basins typically exhibit low infiltration and suboptimal runoff. Greater weighting values were assigned to regions with low to moderate drainage networks due to their presumed favorable groundwater potential. DI Khan drainage density zones can be seen in Figure. 3.



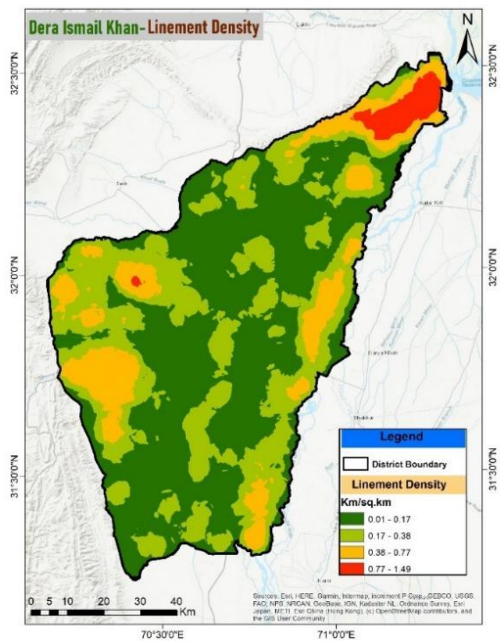


Figure 3. Drainage Density map of study area

Figure 4. lineament map of study area

Lineament density: Lineaments serve as indicators of subsurface defects or fractures that influence groundwater flow by providing channels and basins. Since lineament continuity often signifies permeable zones, a region's lineament density could reveal its groundwater potential ultimately. Using ArcGIS 10.8's density analysis feature, lineament density was calculated and mapped accordingly, with categories ranging from very low (0.01-0.17) to high (0.77–1.49). Zones with high lineament densities were assigned higher weighting values for their groundwater potential estimation. DI Khan lineament density is displayed in Figure. 4.

Slope: The slope map plays an importance critical part in evaluating water infiltration into the ground. More or Steep slopes mean or show high runoff zones, while gentle slopes indicate low

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runoff zones with improved infiltration. One of the most importance parameter for mapping grund water potential zone are slope, because it regulates surface runoff and vertical water percolation, thus influencing groundwater recharge (Kumar et al., 2014). Infiltration has been discovered to be inversely proportional to the slope (Yeh et al., 2009b). The slope map was created to highlight the importance of slopes on precipitation absorption using a 30 m resolution digital elevation model (DEM) from the Shuttle Radar Topography Missions (SRTM). Steep inclines offer little rejuvenation since there is insufficient time for water to permeate the layer and replenish the saturated area during rapid rainfall. Four classes have been assigned to the slope: (0-4.09), (4.09-11.74), (11.74-22.40), and (22.40-69.85). Figure. 5 showcases a D.I. Khan Slope Map.

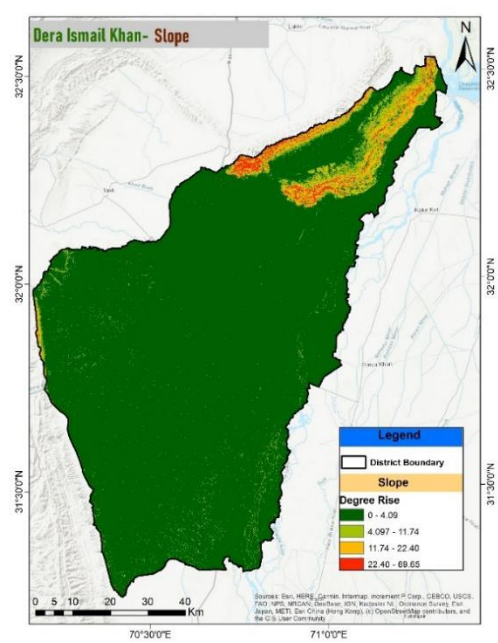

Figure 5: Slope map of study area

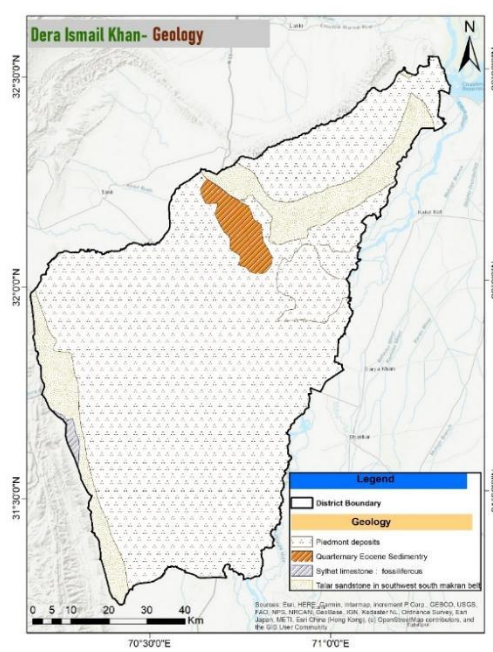

Figure 6: Geology map of study area

Geology. The ground water is very strongly affected by the geology of the area. The study area are consists of the following of majority of rock, out of which the current study is focused on the followings rock types: quaternary Eocene sedimentary, piedmont deposits, Sylhet limestone, and talar sandstone. The piedmont deposits and metamorphosed talar sandstone that make up the region's geological composition are its main features. Groundwater visibility is directly impacted by the geological structure and composition of the rocks. This is manifest on the region's geology map (Figure 6), where definite rocks exhibit resistance to subsurface water intrusion or

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significantly impact the recharge process, while others facilitate water flow and replenish subsurface reservoirs.

Soil Texture: The in the study area's the soil is divided into two main classes based on the characteristic of: clayey, loamy, and partially saline soil with sporadic areas of heterogeneous composition. The distribution of weightage is determined by the soil's ability to retain water and the property's water-bearing capacity. Rocky boulders with shallow soil, clay-rich soil, and clayey sand possess low weight and poor porosity. Conversely, loamy soil has largely contributed to high weightage values due to its heightened permeability (Nasir et al., 2018). Figure 7 illustrates the DI Khan soil map.

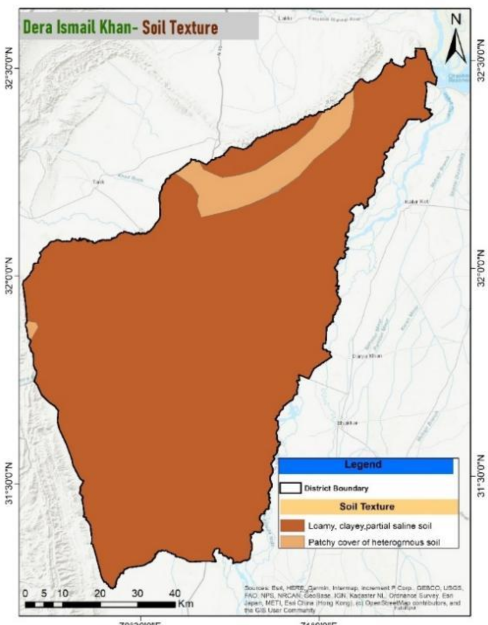

Figure 7: Soil map of study area

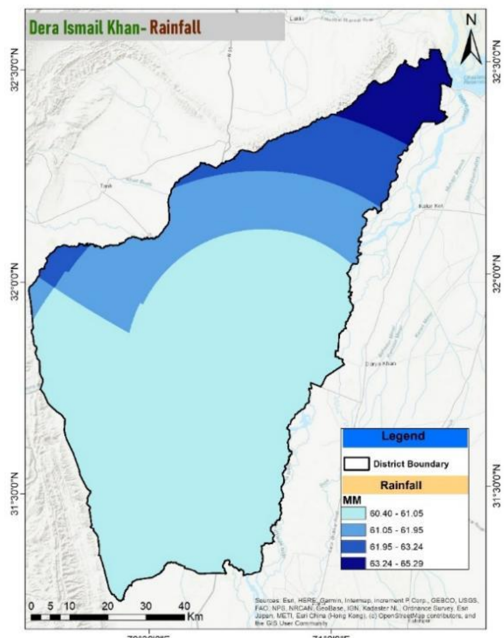

Figure 8: Rainfall map of study area

Rainfall. Rainfall plays an importance role in replenishing groundwater reserves. Local stations collected annual rainfall data for the entire twelve-month period of 2022, which was subsequently averaged. Data from the Peshawar District Meteorological Office was obtained for Met Station DI Khan and Bannu Rainfall stations. After integrating this data into ArcMap 10.8 for interpolation purposes, the output surface was segmented into various zones ranging from 60.40 - 65.29 mm. Appropriate weights were assigned to each zone; higher rainfall classes garnered increased weightage based on their potential to rejuvenate aquifers during the ArcMap reclassification process. The DI Khan rainfall map can be found in Figure 8.

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Land use/Land cover: Evapotranspiration, surface runoff, and infiltration processes are all directly impacted by patterns of land use and cover, and these factors in turn affect groundwater recharge. (Mondal, 2012; Misi et al., 2018). The imagery is categorized into five types based on an analysis of the land use and cover properties of the study area: aquatic bodies, agricultural land, settlements, barren land, and barsati nala and river sand (Figure 9). The majority of the research region is made up of barren land, indicating that a sizable section of the terrain is arid. Water bodies make up very little space(Moodley et al., 2022b). Landsat-8 satellite data for the Rabi Season of 2022–2023 was analyzed using the Random Forest Classifier on the Google Earth Engine platform. Using machine learning methods, Google Earth Engine (GEE) provides a platform for supervised land cover classification. To achieve this, training data was gathered in the field through an Android data collection application. After that, the data was uploaded into GEE to train the Random Forest (RF) Classifier, which was then improved using a brand-new feature weighting strategy and tree selection methodology. The aim of these enhancements was to increase the random forest framework's suitability for categorizing image data that contains many object categories. Each of the several trees that make up the Random Forest multi-way classifier grows by applying some sort of randomization. Estimates of the posterior distribution for different image classes are labeled on the leaf nodes of each tree. Each internal node, meanwhile, is made up of a test that divides the data space in the best possible way for categorization. After an image has been classified through each tree, the leaf distributions that have been reached are combined and assessed(Xu et al., 2012).

	Agriculture	Barren land	Fallow land	Natural	Riverbed	Settlement	Water	Barsati Nala	User
Agriculture	8	0	2	0	0	0	0	0	10
Barren Land	0	5	1	0	0	0	0	0	6
Fallow land	2	0	9	0	0	0	0	0	11
Natural	0	0	2	5	0	0	0	0	7
Riverbed	0	0	0	0	4	0	1	0	5
Settlement	0	0	0	0	0	5	0	0	5
Water	0	0	0	0	0	0	6	0	6
Barsati Nala	0	1	0	0	0	0	0	4	5
Producer	10	6	14	5	4	5	9	4	55

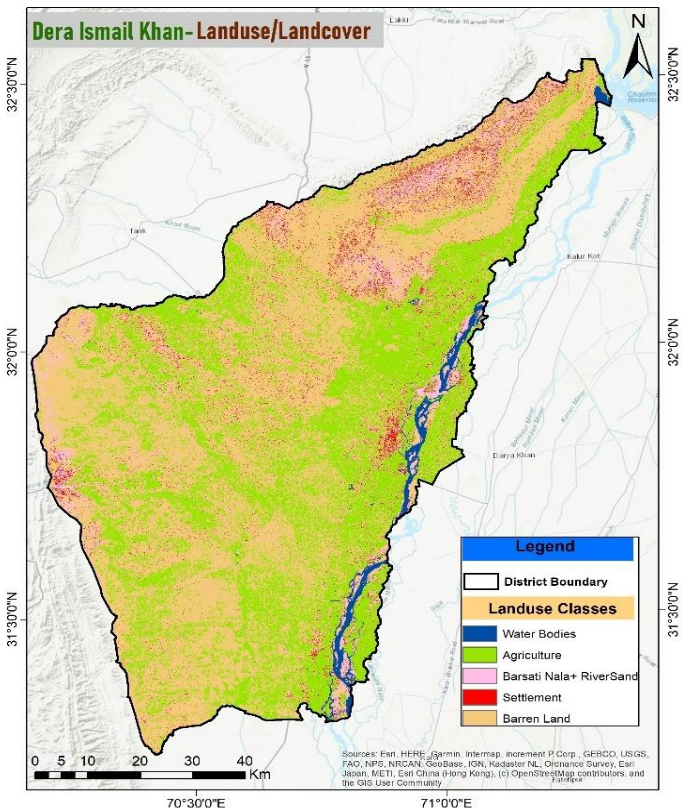

Figure 9: LCLU map of study area

Table 1: Accuracy assessment of the LULC Classified image.

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Overall Accuracy=46/55*100

=83.63%

User Accuracy

Agriculture=8/10*100=80%
Water Body=6/6*100=100%
Natural=5/7*100=71.42%
Built-up=5/5*100=100%
Riverbed=4/5*100=80%
Fallow land=9/11*100=81.81%
Barren land=5/6*100=83.33%
Barsati Nala=4/5*100=80

Producer Accuracy

Agriculture=8/10*100=10%
Water Body=6/9*=66.66%
Natural=5/5*100=100%
Built-up=5/5*100=100%
Riverbed=4/4*100=100%
Fallow land=9/14*100=64.28%
Barren land=5/6*100=83.33%
Barsati Nala=4/4*100=100%

Kappa Coefficient(T)= $(TS * TCS) - \sum(Column\ Total * Row\ Total)\ )/(TS2 - \sum(Column\ Total * Row\ Total)\ ) * 100$= (41*55)- {(10*10) +(6*6) +(14*11) +(5*7) +(4*5) +(5*5) +(9*6) +(4*5)}/ (55*55)- {(10*10) +(6*6) +(14*11) +(5*7) +(4*5) +(5*5) +(9*6) +(4*5)}

=**80.82%**

TS=Total Sample
TCS=Total Corrected Sample

Weighted overlay method. When all parameters are prepared, these themes were then converted to pixels since raster layers serve as the foundation for a weighted overlay analysis. The data will be converted to raster datasets if it is in vector format. The groundwater potential zones were created by superimposing all seven parameter thematic maps using the weighed linear combination (WLC) formula (Agarwal et al., 2013; Kumar et al., 2014). Subscript integers = normalized weight of thematic layer, wi = normalized rank of each feature and Sl = slope, Dd = drainage density, Ld = lineament density, Gg = geology, Lulc = land use land cover, Rf = annual mean rainfall, Lt = lithology, S= Soil.

To determine the four groundwater potential zones, the data was first divided into four groups.

The data classes were reorganized and ranked on a 4-point scale, with 4 denoting the maximum capability for groundwater recharge and 1 denoting the lowest ability. A thorough analysis of the spatial data gathered and the information gleaned from GWPZ articles was used to create this rating system. GIS reclassify was used to reclassify the data using natural divides found in the data. The weighted overlay analysis technique was essential in determining the GWP zones in DI Khan by utilizing feature classes and raster data. By assigning weights and ranks to variables that affected the region's capacity for groundwater recharge, the analysis aimed to categorize GWP zones, as shown in Table 5. Each thematic layer was assigned a MIF weight, producing a cumulative weight that is shown as normalized principal eigenvectors in the table. The Weighted Overlay Analysis tool in GIS was then used to import these weights. Equation (3) was used to calculate the groundwater potential index. It took into account all thematic layers and elements, with X standing for significant influences and Y for minor ones (Ali et al., 2024a).

. $$[X+Y \div \sum(X+Y)] \times 100$$ (Magesh et al.2012).

Where X represents the main influence of factors while Y represents minimal impact of factors.

Table no 2. Minor and Major influence of parameters)

Selected Parameter	(High) Major Effect (A)	(Low) Minor Effect (B)	Relative effect of Each Parameter (A+B)	Proposed weight of Each Influencing Parameter
LCLU	2+2+2	1+1	8	20
Lineament Density	2+2	1+1	6	15
Topography (Slope)	2+2	1+1	6	15
Drainage Density	2+2	1+1	6	15
Soil type	2	1+1	4	10
Geology	1	1	2	5
Rainfall	2+2+2	1+1	8	20
			∑40	100

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Table 3. illustrated all thematic layers and score assigned to maps

Influencing Parameters	Sub Classes Within Influencing Parameter	(Qualitative Rank)	Proposed weight of Each Influencing Parameter	Groundwater Prospects (Quantitative Rank)
Land use/ Land cover	Water body Agriculture land Barsati Nala+River Sand Settlements Barren land	Very high High Moderate Low Very low	20	8 5 4 2 1
Rainfall in mm	60.40 -61.05 61.05 -61.95 61.95–63.24 63.24– 65.29	Very Low Low Moderate High	15	7 5 2 1
Slope in Degree	0 – 4.09 4.09 – 11.74 11.74 – 22.40 22.40 – 69.65	High Moderate Low Very low	15	7 5 2 1
Drainage density in km/sqkm	0 – 0.15 0.15 – 0.30 0.30 – 0.46 0.46 – 0.83	High Moderate Low very low	15	7 5 2 1
Geology	Talar Sandstone Piedmont Deposits Rocks Quaternary Eocene Sedimentary Rocks Sylhet Limestone: fossiliferous	High Moderate Low Very Low	10	4 3 2 1
Lineament Density in Km/sqkm	0 – 3.60 3.60 – 7.17 7.17 – 10.75 10.45 – 14.44	High Moderate Low Very low	15	7 5 2 1
Soil	Loamy ,Clayey and partial saline soil Patchy cover of heterogenous soil	High Moderate	10	4 3 2 1

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Assumed weights of various layers.

Based on current literature, weight and rank are assigned to each assumption or its class.

Weights are assigned a number between 1 and 8, where 8 indicates the region most likely to have potential groundwater and 1 indicates the least amount of potential groundwater. Four groups comprised the majority of the layers. Four classes correspond to the geological level, four classes correspond to the drainage level, and five categories correspond to the extent of land use cover.

Prior study has examined the characteristics of all parameters and assigned a weighting system based on their relative benefits in relation to the availability of subterranean water. Prior to doing a weighted overlay analysis, confirm that each layer is in the comparable reference system to the projected coordinate system WGS 1984 UTM Zone 43N.

After preparing all of the raster layers—which are necessary components for weighted overlay analysis—each map was converted to cell format and then used to illustrate Groundwater Suitable Sites of Research Region. So, using the spatial analyst capabilities in ArcGIS, vector data was converted into raster datasets. For every raster input into a weighted overlay service, the geo TIFF format was employed. In the process of appointment, powers and positions were awarded to parameters and related subclasses. The "weighted overlay" tool was utilized to perform an overlay analysis using the overlay toolset found in ArcGIS's spatial analyst capabilities. With the use of a common measuring scale, this tool layered several raster's and then weighted each one based on significance, producing an output layer with values ranging from 1-4. As previously stated, values of 4 and 1 respectively represented very poor and exceptional freshwater potential locations. In general, four classes with varying numbers of subgroups were created by reclassifying the layers.

Based on prior research, the strengths of each parameter were carefully considered and weights were assigned based on how they affected groundwater availability. This study used the projection reference system WGS 1984 UTM Zone 43N to ensure that all rasters shared the same coordinate system prior to performing a weighted overlay analysis. In the end, the groundwater potential zone map best captures the groundwater situation in the research region.

Figure 10, shows the essential parameters after they have been appropriately weighted based on how accessible they are in the field. The results of the weighted overlay analysis have been

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categorized into four groups: high, moderate, poor, and extremely poor, based on the groundwater availability. The area of 1434.132 sq.km has been found to have a high; 4546.379 sq.km is considered moderate; 1222.989 sq.km is considered poor; and 227.974 sq.km is considered very poor.

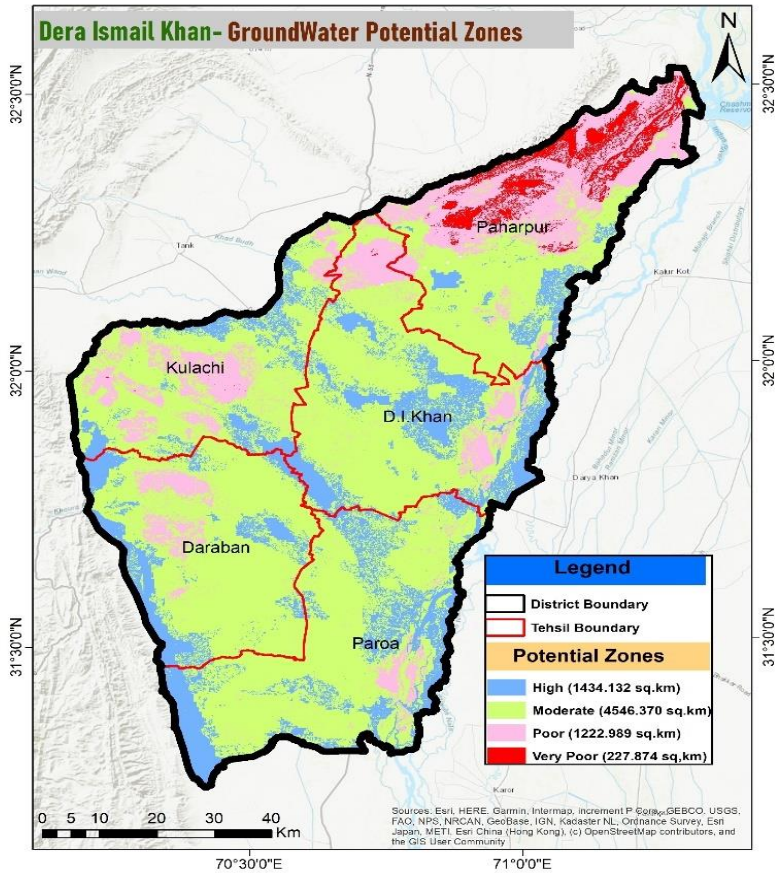

Figure 10: Groundwater potential zones map

Verification of the Results:

An in-depth field analysis was conducted to determine the water table depth across the study area. Handheld GPS devices were utilized to collect coordinates for 45 distinct wells, tube wells, and hand pumps, with their depths recorded in feet. Our survey revealed that water depths vary from a shallow 25 feet to an impressive 380 feet. The well depths were divided into four categories: (0-100), (100-200), (200-300), and (300-400) feet. The well data were superimposed atop the designated groundwater potential regions layer (Figure 11), functioning as a reference point for precision calculations. The cross-verification method was employed to confirm the accuracy of the

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weighted superimposed results. Groundwater potential was higher in areas with shallow, accessible water tables, such as Tehsil DI Khan and Paroa which fall within very high groundwater potential regions. In contrast, areas like Paharpur fall into very poor groundwater potential zones due to deeper water tables. The overlay analysis showed that most wells with shallow and moderate groundwater depths are situated within the very high and high groundwater potential zones

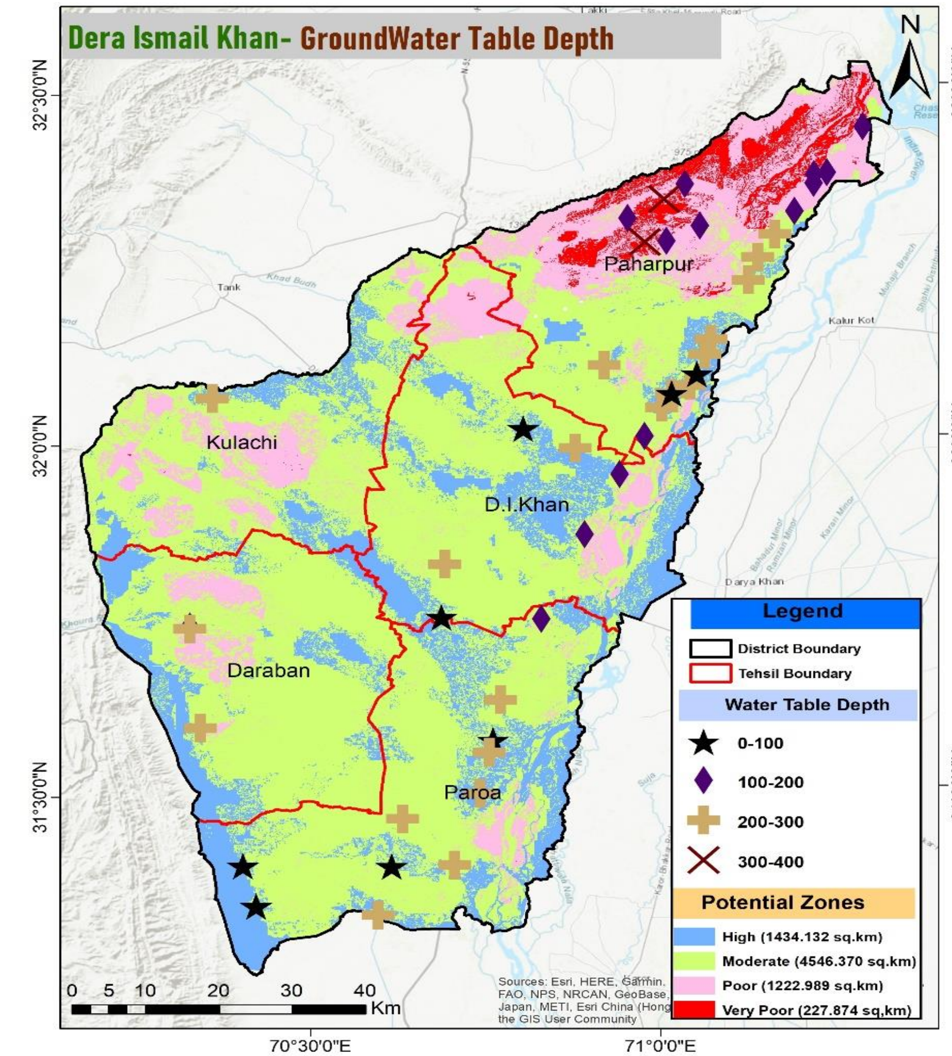

Figure 11: Groundwater potential zones overlay by existing water Table depth.

Conclusion

It has been noticed that using GIS and Remote Sensing, with Multi Influencing Factor techniques for delineation the freshwater potentiality for the development of the agricultural sector, drinking

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and domestic use in DI Khan District. GIS is an efficient way to save time, money, and labour while enabling rapid decision-making towards sustainable management of water root. Geology, lineament density, drainage density, slope, soil, land-use, and rainfall thematic layers were produced using satellite information and topographic maps. According upon groundwater accessibility, the weighted overlay analyzed data was grouped into four categories: high, moderate, poor, and very poor. According to the classification results, the region of 1434.132 sq.km has been discovered to have a high; while moderate is 4546.379 sq.km, 1222.989 sq.km is poor and very poor is 227.9 sq.km. Figure (5.8) depicts the final map of the ground water potential zones.

Recommendations

The assessment demonstrates that all variables fall within acceptable parameters; however, many areas exhibit moderate availability due to climate change and recurring rainfall recharging groundwater aquifers. It is recommended that water extraction facilities be established at key district locations to monitor water table levels regularly and ensure availability for barani agriculture areas in tehsils Daraban, Kulachi, Dikhan, Paroa, and Paharpur. Public awareness campaigns such as walks and seminars should be organized to increase understanding of water issues in the area. Proper oversight must also be implemented to safeguard both above ground and freshwater resources, enhancing the preservation and management of water resources. Engineers, planners, and decision-makers can utilize maps generated by the MIF Approach to allocate groundwater in accordance with the national water policy. The integrated GIS and RS methodologies can streamline the identification of groundwater zones across various parts of the country. In addition, incorporating characteristics such as surface and subsurface Lineament, Geomorphology, Lithology, Topography, Soil map, Aquifer resistivity data, Hydro geomorphology, and surface water body maps can further facilitate groundwater allocation in other expansive areas. Based on the findings of this study and the groundwater resistivity data acquired from provincial irrigation department zones, it is advised to identify specific areas within the predominantly barani district. Here, the Chashma Right Bank Canal (CRBC) command area only supplies surface water, and a portion of the district in the north-west Gomzal Zam command area follows suit. By ensuring water accessibility throughout the entire agricultural region of the

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district, the issue of food scarcity in Khyber Pakhtunkhwa can be effectively addressed. With its untapped potential for crop growth, Dera Ismail Khan has the capacity to sustain the province's entire food requirements.

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