Urmia University

Journal of Geography and Regional Future Studies
Vol. 3, Special Issue, Winter, 2026
Online ISSN: 2981-118X
https://grfs.urmia.ac.ir/

Delineation of Groundwater Potential Zones Mapping Using MIF and Remote Sensing Techniques in an Agricultural Production Area Karezat Tehsil, District Pashin of Pakistan

Abdull Basit[1], Asma Khan Kakar[2], Nadia Shahzada [3] and Niamat Ullah[4]

[1] Centre of Agriculture and Bioscience International, (CABI), Quetta, Balochistan
[2] Department of Geography and Regional Planning, University of Balochistan, Pakistan
[3] Department of Geography and Regional Planning, University of Balochistan, Pakistan
[4] State Key Laboratory of Mountain Hazards and Engineering Resilience, Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu 610299, China.
[4] University of the Chinese Academy of Sciences, Beijing 100049, China.
[4] Spatial Decision Support System (SDSS), Lab (NCGSA), Balochistan University of Information Technology, Engineering and Management Sciences (BUITEMS), Quetta 87300, Pakistan.
[4] Department of Colleges, Higher & Technical Education, Quetta, Balochistan, Pakistan.

ARTICLE INFO

Article type:
Research Article

Received:
2025/10/27
Accepted:
2026/02/09
pp:
23-32

Keywords:
Multi Influencing Factor;
Groundwater Potential Zones;
Hydrology;
GIS;
Remote Sensing;
Groundwater.

ABSTRACT

Background: The most important supply of freshwater on Earth, groundwater is essential for meeting industrial, agricultural, and residential demands. Pakistan's limited groundwater supplies are under tremendous strain due to the country's fast population increase and agricultural expansion.
Objectives: This study's principal goal was to use geospatial tools to identify groundwater potential zones (GWPZs) in a Pakistani agriculturally productive area. The study's objectives were to classify the region according to its groundwater potential and evaluate the variables affecting groundwater occurrence.
Methodology: The study used ArcGIS 10.8 software to integrate geospatial analysis with the Multi-Influencing Factor (MIF) technique. Geology, soil type, slope, rainfall, lineament density, drainage density, and land use/land cover (LULC) were the seven thematic layers that were chosen as the main factors affecting groundwater availability. These factors were combined using weighted overlay analysis to create a map of the groundwater potential zone.
Results: There are three main groundwater potential zones in the study area: high, poor, and very poor. A little over 315 km² of the land was found to be in the high potential zone, 1181 km² in the low potential zone, and 30 km² in the extremely poor potential zone, according to the spatial distribution. The findings demonstrate how the groundwater supply varies geographically throughout the research area.
Conclusion: The study shows that using the MIF method in conjunction with GIS and remote sensing techniques offers a dependable and effective way to identify possible groundwater zones. The results can help planners, legislators, and managers of water resources develop and manage groundwater sustainably, especially in areas where water shortage is growing.

Citation: Basit, A., Kakar, A. K., Shahzada, N., & Ullah, N. (2026). Delineation of Groundwater Potential Zones Mapping Using MIF and Remote Sensing Techniques in an Agricultural Production Area Karezat Tehsil, District Pashin of Pakistan. *Journal of Geography and Regional Future Studies*, 3(Special Issue), 23-32.

DOI: https://doi.org/10.30466/grfs.2026.56670.1171

Corresponding author: Asma Khan Kakar, **Email:** asmahakeem12@gmail.com, **Tell:** +923402374319

1. INTRODUCTION

Water is essential to life on Earth and has a major impact on every stage of our environment (Westall & Brack, 2018). The need for groundwater is growing as a result of the current surface water supplies' inability to meet all of the demands for agriculture, household, and industrial use (Priyan & region, 2021). Increased ground water use and surface water shortages are the results of economic growth, climatic change, high population density, and unequal distribution of water resources (Arsiso et al., 2017). It is estimated that around 30.1% of freshwater on Earth comes from groundwater. It is commonly used for household purposes and is one of the most important sources of freshwater (Mishra, 2023). Just 3% of the water on Earth is thought to be fresh, with the remaining 97% being ordinary saline water that is unfit for human consumption. Glaciers and ice sheets hold 68.7% of the fresh water that is available (Mishra, 2023). The world's need for freshwater resources has grown dramatically as a result of fast industrialization and population expansion. As a result, groundwater extraction is now a crucial component of many water management strategies, especially in rural areas (Siegel, 2021).

A region's "groundwater potential" is the quantity of groundwater that is accessible there and depends on a number of hydrogeological and hydrological parameters (Díaz-Alcaide & Martínez-Santos, 2019). The amount of freshwater on Earth is constantly abundant, although it fluctuates in time and location and isn't always appropriate for all purposes (Fleming, 2019). In both natural and artificial settings, groundwater is a vital natural resource for the reliable and affordable supply of drinkable water (Scanlon et al., 2023). Thus, groundwater supplies are essential to both terrestrial and marine ecosystems as well as human well-being (Naiman & Dudgeon, 2011). Presently, over 34% of the total yearly water supply comes from groundwater. For the sustainable use of this natural resource, effective groundwater management is therefore crucial (Scanlon et al., 2023).

Remote sensing (RS) and geographic information systems (GIS) are useful instruments for identifying possible groundwater locations (Tiwari & Shukla, 2015). In recent years, the extensive use of traditional maps, corrected ground truth data, and remote sensing data (satellite data) has made it easier to establish reference point information for potential groundwater locations. (Masood et al., 2022). The capacity of remote sensing (RS) to quickly offer temporal, geographic, and spectral availability of data covering huge and inaccessible places has made it a valuable tool for monitoring, conservation, and evaluation of groundwater resources (Shaikh & Birajdar, 2024). Remote sensed data quickly and effectively determined the baseline information on the groundwater influencing parameter such as geology, geomorphology, LULC, drainage and lineament, etc. that govern the occurrence and flow of groundwater (Seelan, 2015). In the process of mapping groundwater potential areas several parameters such as geology, soil type, rainfall, elevation and slope, faults and lineament, drainage patterns and groundwater table distribution play a vital role (Hussein et al., 2017).

Groundwater resources are crucial to Pakistan's agriculture-based economy, particularly in areas with limited surface water supplies (Khair et al., 2021). Although there are substantial water supplies from the Indus Basin Irrigation System, groundwater is still essential for supplying agricultural needs in non-canal regions (Usman et al., 2016). For this reason, planning effective water resource use requires mapping and identifying groundwater potential zones (GWPZ) (Suryawanshi et al., 2023).

The largest province in Pakistan by area, Balochistan, suffers from acute water scarcity as a result of inadequate water management, high evaporation rates, and little rainfall (Akhtar et al., 2021). Groundwater is the lifeline of its rural economy, sustaining agriculture and livestock production. However, a systematic approach to groundwater evaluation is required due to the concerning problems of diminishing water tables and worsening water quality in several parts of Balochistan (Aftab et al., 2018). The study offers important new information about the district's hydrogeological parameters, agricultural sustainability, and socioeconomic susceptibility to water scarcity from the standpoint of Pishin Studies (Kakar et al., 2016). The study's findings can help farmers, local government representatives, and legislators implement effective groundwater management techniques that will guarantee agricultural output for the long run (Shah, 2014).

There are still many unanswered questions, especially regarding the integration and validation of multi-influencing factor (MIF) models in Pakistani agricultural landscapes, despite the increasing use of GIS and remote sensing techniques in groundwater potential mapping (Nazir et al., 2024). The majority of current research either concentrates on evaluations at the regional level or uses a restricted set of hydrogeological criteria, ignoring the intricate relationships among topography, soil composition, land use, and climate that have a significant impact on groundwater recharge (Owuor et al., 2016).

Furthermore, there aren't many site-specific, high-resolution assessments that combine field-based validation with remote sensing data to improve model correctness and dependability (Saiz-Rubio & Rovira-Más, 2020). Developing accurate groundwater potential maps that can aid in the sustainable management of water resources and agricultural productivity in Pakistan's water-stressed areas requires filling in these gaps.

2. METHODOLOGY

2.1 Study area

Karezat is a Tehsil (administrative entity) situated 70 kilometers north of Quetta, the provincial capital of Balochistan province, Pakistan, in the Pishin district. 30.620682° north latitude and 67.327021° east longitude are its geographic coordinates. (Qasim & Kakar, 2021) (Figure 1). Tehsil Karezat is a rural area with more than 80% rural population. Karezat is a local word which means stream and it has a total area of 1544 km2 becoming the largest the largest Tehsil of Pishin with an elevation of about 3,137 meters (Qasim et al., 2011). The main cultivated fruits in the area are apple, apricot and pomegranate, whereas, the well-known cultivated crop is wheat. Karezat experiences 22.4°C and 260.75 mm of precipitation on average each month, indicating an arid to semi-arid environment (Qasim et al., 2011). The study area Karezat Tehsil is facing scarcity of water problems from last few decades.

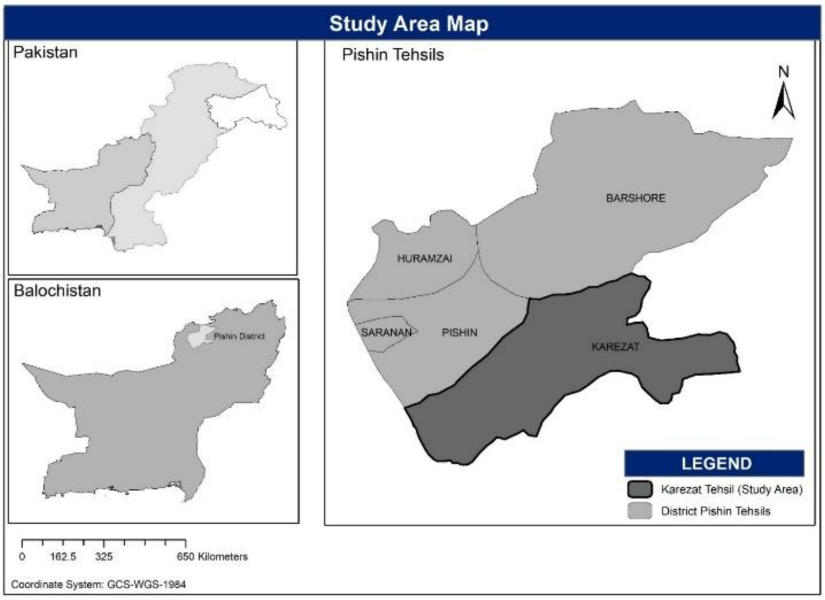

Fig 1. Map showing the location of study area, Tehsil Matta district Swat

2.2 Datasets and Methods

Identification of potential groundwater areas through a multi-influencing factor method is the main objective of the study. This method entails collecting the required data from multiple departments and utilizing ArcGIS 10.8's weighted overlay analysis technique to analyze it. The weights of the several influencing parameters were then established using multi-influencing factor (MIF) approaches.

2.3 Assigning Weights and Ranks to Parameter

The seven parameters that make up the MIF Model are geology, lineament, soil, slope, rainfall, land use/cover, and drainage density. In order to identify ground water, we first choose these characteristics. Second, apply weights and scores to these chosen factors following the brief literature review. Each thematic layer's component parameters will be graded and weighted according to their significant, minor, and non-influence on ground water potential. Score 2 were given to the major, influence (A), score 1 were given to the minor influence (B) and score 0 was given to no influence (Table 1). The cumulative score ($A + B$) of both major (A) and Minor (B) influence are calculated according to formula (Equation 1). This relative effect is further used to calculate the weight of each influencing parameter (Shaban et al. 2006; Yeh et al. 2009; Adham et al. 2010; Rashid et al. 2011; Mukherjee et al. 2011; Magesh et al. 2012;Gumma and Pavelic 2012). Formula through which the weight for each influencing factor were calculated is

$$(A + B)/\sum (A + B) \times 100 \qquad \text{Eq. (1)}$$

where A and B stand for the major and minor influences, respectively.

After dividing the weights of the parameters according to their influence, each of the seven influencing factors' subclasses was given a rank. Each influencing factor's weight and rank for its subclasses are displayed in Table 2. Additionally, ArcGIS 10.8.1 was used for analysis. The ARC Map 10.8.1 software's geographical analysis expansion allows you to mix scores from all thematic levels of influencing elements. The output result of employing the weighted overlay tool in the spatial analyzer extension was divided into three categories: High, Moderate, and Low.

Table 1. Parameters' minor and large effects

Parameter	Major Effect (A)	Minor Effect (B)	Proposed Relative Effect (A+B)	Proposed weight of Each Influencing Parameter
Land use/ Land cover	2+2+2	1+1	8	20
Lineament Density	2+2	1+1	6	15
Slope	2+2	1+1	6	15
Drainage Density	2+2	1+1	6	15
Soil	2	1+1	4	10
Geology	2	1+1	4	10
Rainfall	2+2	1+1	6	15
			∑	∑

2.4 Weighted Overlay Analysis

Table 2. Rankings and weights of the many factors affecting groundwater recharge in the research region

Parameters	Sub Classes	Qualitative Rank	Weights	Rank
Land use/ Land cover	Vegetation Settlements and Open Land Rocks Water Barren land	Moderate Low high Very low Very high	20 20 20 20 20	8 5 4 2 1
Rainfall in mm	1.0 -2.5 2.5 _ 4.0 4.0 – 5.5 5.5 – 7	High Moderate Low Very low	15	7 5 2 1
Slope in Degree	0 – 6.5296 6.5296 – 13.91089 13.91089 – 24.1311 24.1311 – 723934	High Moderate Low Very low	15	7 5 2 1
Drainage density in km/sqkm	1 – 2 2 – 3 3 – 4 4 – 5	High Moderate Low very low	15	7 5 2 1
Geology	. Rocks with sediments from the Miocene and Oligocene . Rocks with Jurassic sediments . Alluvium . Rocks of the Pleistocene sediments . Late Tertiary and Early Intrusive Cretaceous rocks . Rocks with sediments from the Eocene and Miocene . Volcanic rocks of the Pleistocene . Rocks with sediments from the Pliocene and Miocene	High Moderate Low Very Low Not aligned to each other	10	4 3 2 1
Lineament Density in Km/sqkm	1– 2 2 – 3 3 – 4 4 – 5	High Moderate Low Very low	15	7 5 2 1

Parameters	Sub Classes	Qualitative Rank	Weights	Rank
Soil	**Mountains:** Very shallow rock outcrops and loamy Soil **Valleys:** Mainly loamy soil **Mountains:** Rock outcrops with very potcky cover of heterogeneous soil **Valleys:** Mainly loamy, part pravelly soil (Repeated)	High Low	10	4 3 2 1

3. RESULTS

3.1. Generation of Input Parameters

Elevation: Elevation refer to height of space from mean sea level. Water tends to store in lower topography rather than the higher the topography. Higher the elevation, lesser is the ground water potential and vice versa. Elevation also have role in the water table, the study area is located between 1490 to 3218 meters above sea level. Elevation map shown in figure (3a).

Drainage Density: SRTM digital elevation model (DEM) with spatial resolution of 30 m is used to generate Slope, Drainage and Elevation of study area. For Slope and Elevation there are special tools available in ArcGIS 10.1. An area's groundwater penetration and water runoff are described by the drainage density. The drainage network and drainage density data for this investigation were created using SRTM DEM data at a resolution of 30 meters. The drainage density was computed by extracting the stream network using hydrology tools. Very low, low, moderate, and high were the classifications given to the regions. drainage density zones, as depicted in (3)b. Areas with low drainage densities see comparatively low levels of infiltration and runoff, and vice versa. The zones with low to moderate drainage densities were assigned a greater weighting value because they are thought to have excellent ground water potential.

Lineament density: The presence of ground water operating as canals and reservoirs is influenced by lineaments, which are indicators of subsurface faults and breaches. An area's lineament density can eventually reveal its groundwater potential because lineament typically indicates permeable zones. The liniment for the research region is made with the sentinel-2 Pan sharpened reflected band from PCI Geomatica 2020. The lineament was extracted using software, and its density was determined using ARC GIS 10.4's density analysis tool. The map of lineament density is shown in figure (3c). The region was categorized into four groups: extremely low, low, moderate, and high. A larger weighting value was assigned to high density zones, which were categorized as having a high potential for ground water.

Soil: The study area's soil map came from the Pakistani Soil Survey, and a thorough analysis of pertinent literature was used to ascertain the traits and efficacy of various soil types in promoting groundwater recharge. Four main soil classes were identified throughout the region using the soil thematic layer. The most common soil types in mountainous regions are rock outcrops and very shallow loamy soils, which have little capacity to retain water and infiltrate it, making them insignificant contributors to groundwater recharge. Rock outcrops with a highly patchy overlay of diverse soils make up another type in mountainous areas. Because hard, impermeable surfaces predominate, infiltration is further restricted. The loamy soils that make up the valley regions, on the other hand, have a moderate permeability and are good for groundwater recharge. In addition, there are loamy to gravelly soils in some of the valleys. Because gravel increases penetration rates, these areas are better suited for recharging aquifers than the surrounding hilly terrain. Fortunately determine weights based on the composition and water-holding capability of the soil. Rocky outcrops where the soil is shallow and contains clay and clayey sand have been given a low weight due to their poor permeability. The main source of high weight values has been loamy soil due to its high porosity and permeability.

Land use/Land cover: A key factor in groundwater recharge is land cover and use. The land cover and land use layer for this study was created using Sentinel-2 (2020) images with a resolution of 12 meters. This approach of supervised classification was carried out using Arc GIS 10.4. The study's findings were categorized using the supervised classification approach into five classes: vegetation, settlements and other areas, rocks, water, and barren terrain. This is the LCLU Map in figure (3e). The study area's image categorization reveals that the Tehsil was covered in bare soil and plants.

Geology: The distribution and occurrence of ground water are significantly influenced by geology, one of the main reasons. Eight different kinds of rocks are found in the current study region.

- Miocene and Oligocene sedimentary rocks
- Jurassic sedimentary rocks

- Alluvium

Rocks with sediments from the Pleistocene. intruding rocks from the Early Tertiary and Late Cretaceous periods. sedimentary rocks from the Eocene and Miocene. volcanic rocks of the Pleistocene. sedimentary rocks from the Pliocene and Miocene periods.

In terms of geology, the research region is dominated by sedimentary rocks from the Eocene and Miocene as well as the Oligocene and Miocene. Groundwater availability is significantly impacted by this type of rock and geology; some rocks have the ability to permit water to percolate underground and play a part in this process, while others have a strong resistance to this process. M.P. Searle and M. Asif Khan's geological map of northern Pakistan served as the basis for the current study's geology map. After being digitalized from the original map, the map was classed into the main categories of rocks. The geology map is displayed in figure (3f).

Slope: One of the most crucial elements that directly influences how much precipitation can penetrate is slope. Furthermore, because water passes swiftly from the surface after rainfall, providing little time for percolation to the surface and replenishment of the inundated zone, sharp slopes result in reduced recharge. Using ARC GIS spatial analyzer, a slope map with a 30 m resolution was created for this investigation from SRTM DEM. Figure (3g) displays a slope map with four classifications assigned to it. Moderate (13.91089 to 24.1311), high (24.1311 to 723934), low (6.5296 to 13.91089), and very low (0 to 6.5296).

Rainfall: One of the main sources of groundwater availability in the water cycle is rainfall. Based on equal intervals, the study area was divided into four zones, and each class was given the appropriate weight. The Pakistan Metrological Office in Karachi provided the rainfall data for all seven metrological stations. The rainfall data is interpolated spatially in ARC Map 10.2.1. From the interpolated data, four groups were produced: 1.0–2.5 mm, 2.5–4.0 mm, 4.0–5.5 mm, and 5.5–7 mm. The map of rainfall is shown in Figure 3h.

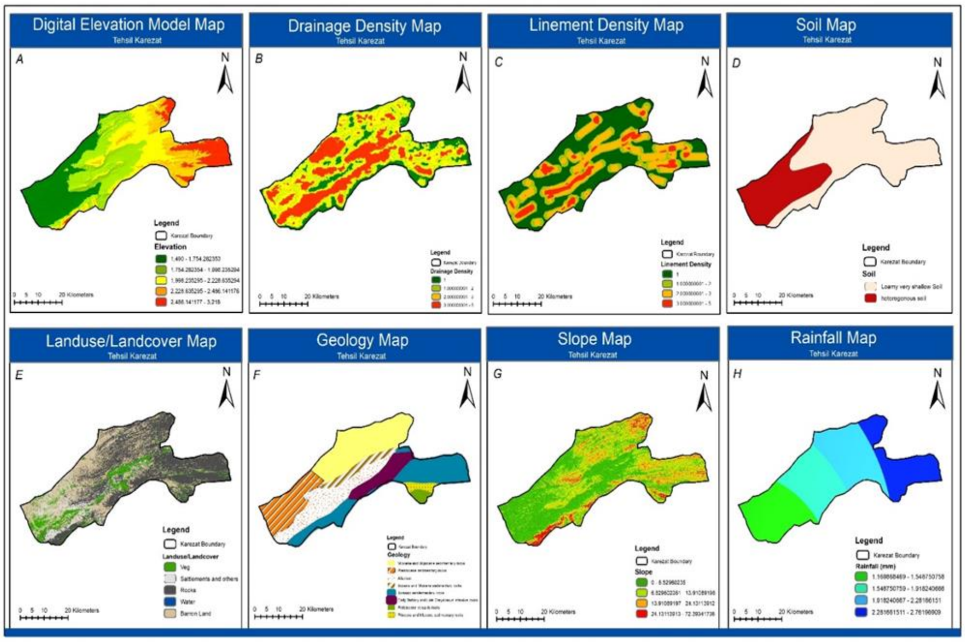

Fig 3. Generation of Input Parameters

3.2. Delineating groundwater potential areas

Once the primary characteristics were given the proper weights based on their impact on field conditions and groundwater occurrence, the final groundwater potential zones map was produced. This map depicts the research area's total groundwater situation, as shown in Figure 4. By integrating multiple thematic layers, the weighted overlay analysis in GIS facilitated the visualization and identification of locations with varying groundwater potential based on the combined influence of multiple parameters, including lineament density, drainage density, rainfall, slope, soil, geology, and land use. Based on the weighted overlay analysis results, groundwater potential was classified as very high, high, moderate, and poor. Permeable soils, high lineament density, gentle slopes, and other favorable geomorphological and hydrological conditions are typically found in areas designated as "very high" and "high" potential zones. On the other hand, "moderate" and "poor" zones are associated with areas that have unfavorable geological formations and a restricted capacity for infiltration. In addition to being a useful tool for planning and managing water resources sustainably within the research region, this categorization offers a clear understanding of the spatial variance in groundwater availability.

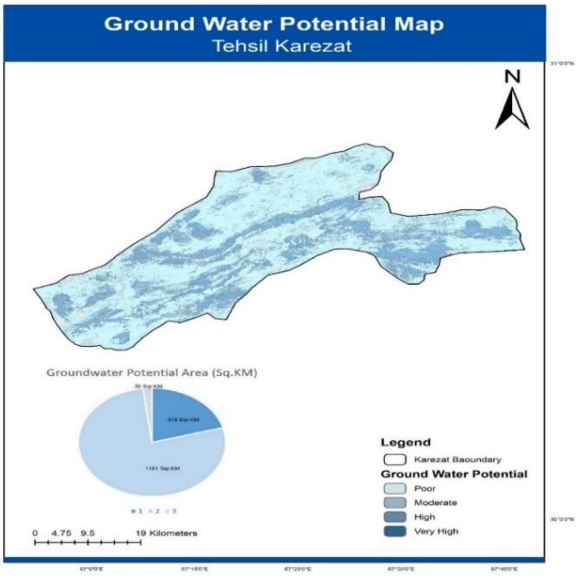

Fig 4. Ground water zones in Karezat

3.3 Verification of the Model

A field survey was conducted to collect the water table depth throughout study area. A handheld GPS were used to collect the coordinates of 43 different Tube wells and their depth were noted in feet. According to our survey the water depth is ranging from very low 250 feets to very high 900 feets. The well depth was divided into three classes like (250-350), (350-450) and (450>) feets. The well data were overlayed on top of delineated groundwater potential zones layer (Figure. 5). This well data ware used as reference point to calculate the accuracy. The cross- verification method was used to check the accuracy of weighted overlay result. According to well depth in study area the ground water potentiality was high mostly in mountainous areas of Rodh malazai. Union Councils Surkhab, Khanai Baba, Bostan, and Murgha Zakaryazai are also located in areas with very high ground water potential, and their water tables are also very shallow. In contrast, Khanozai 1, Khanozai 2, and Bershore are located in areas with very poor ground water potential, and their water tables are also very deep. The overlay analysis found that most wells with shallow and moderate groundwater depths fall inside the very high and high groundwater potential zone.

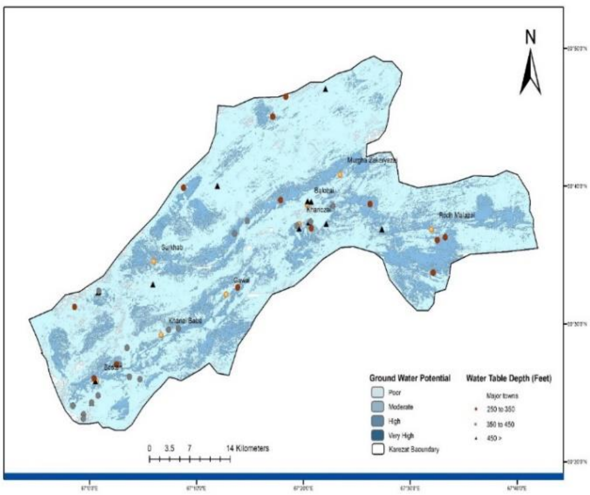

Fig 5. Groundwater potential zones in Karezat Tehsil, Pakistan

4. DISCUSSION

In Pakistan's agricultural production area, the delineation of groundwater potential zones utilizing remote sensing and GIS-based Multi-Influencing Factor (MIF) approaches offers important insights into the availability and spatial distribution of groundwater resources (Ehsan et al., 2024). Through the integration of multiple thematic layers, such as slope, geology, soil, drainage density, land use/cover, rainfall, and lineament density, a comprehensive assessment of the factors impacting the occurrence of groundwater was made feasibl (Fagbohun, 2018). The study demonstrates how the MIF method, as opposed to conventional single-parameter approaches, effectively assigns relative weights to each parameter based on their hydrological value, improving the accuracy of groundwater potential mapping (Anbarasu et al., 2020).

Groundwater potential was shown to be higher in regions with high lineament density, alluvial deposits, moderate slopes, and agricultural land cover (Hussein et al., 2017). These areas correlate to areas with higher potential for aquifer recharge and infiltration rates. Low vegetation cover, hard rock formations, and steep slopes, on the other hand, were shown to have poor groundwater potential zones because of their limited ability for recharge (Achu et al., 2020). Policymakers and managers of water resources must use this spatial differentiation to identify areas that should be prioritized for groundwater investigation and sustainable use, particularly in areas that rely significantly on agriculture (Mbamalu, 2024).

The dependability of the MIF model and GIS-based technique was validated by comparing the calculated groundwater potential zones with the available borehole yield data, which showed a significant correlation (Bhattacharya et al., 2021). This illustrates how combining remote sensing data with GIS analysis can greatly cut down on field investigation expenses and time while preserving a high level of accuracy in estimations of groundwater potential (Shaikh & Birajdar, 2024). Additionally, the results were more dynamic and current due to the enhanced spatial representation of hydrological variables brought about by the use of satellite images for rainfall and land use estimation (Wagner et al., 2019).

The study also highlights how anthropogenic activities, such over-extraction of groundwater and changes in land use, affect groundwater recharge. Over-irrigation and uncontrolled tube well installation have caused groundwater levels to drop in agricultural areas. As a result, determining high and moderate potential zones can help direct water management plans, encourage artificial recharge techniques, and stop overexploitation in vital regions (Kodihal & Akhtar, 2024). Water resource planning that incorporates GIS and remote sensing thereby promotes rural livelihood security and sustained agricultural output. Overall, this study shows how groundwater exploration and management in Pakistan's agricultural landscapes can greatly benefit from GIS and MIF-based modeling. Future studies could concentrate on adding climate change scenarios, groundwater depth, and rainfall variations over time to increase the robustness of the model. The accuracy was calculated using this well data as a reference. The accuracy of the weighted overlay result was examined using the cross-verification approach. The study area's ground water potentiality was high, primarily in the hilly regions of Rodh Malazai, based on well depth.The study offers a scientific basis for decision-making and emphasizes the necessity of implementing cutting-edge geospatial technology for effective groundwater management in other Pakistani regions dealing with comparable hydrogeological difficulties (Shaikh & Birajdar, 2024).

5. CONCLUSION

In Karezat tehsil Pishin zones, groundwater potential may be effectively and economically defined using remote sensing and geographic information systems. Organizers and local authorities may get immediate information about which regions are suitable for groundwater investigation by incorporating the seven thematic layers of drainage density, slope, rainfall, soil, geology, lineament density, and land use/cover, according to the paper. It has been demonstrated that employing remote sensing, GIS, and MIF approaches to define the groundwater potential zones in Karezat tehsil efficiently saves labor, money, and time. This makes it easier to make decisions quickly for the sustainable management of water resources. The theme layers were created using satellite photos, topographical maps, and GPS data. The findings of weighted overlay analysis and groundwater availability have led to the establishment of three classes: high, poor, and severely poor. The classification results indicate that the 315 km² area has a very high 1181 km². At 30 km2, the ground water potential is incredibly low. The final ground water potential zone map. Mapping groundwater potential zones using RS and GIS is one of the primary techniques and instruments for the efficient and regulated development of groundwater resources.These maps are used to create and manage groundwater by planners, experts, and policy and decision makers.

DECLARATIONS

Funding: “This research received no external funding”.

Authors' Contribution: The article was written by Nadia Shahzada and Asma Khan Kakar. Niamat Ullah and Abdul Basit contributed to the study's design.

Conflict of Interest: The authors declare that they have no conflicts of interest.

Acknowledgments: The authors sincerely thank the reviewers for their insightful criticism and helpful suggestions on the manuscript.

REFERENCES

Achu, A., Reghunath, R., & Thomas, J. (2020). Mapping of groundwater recharge potential zones and identification of suitable site-specific recharge mechanisms in a tropical river basin. J Earth Systems Environment, 4(1), 131-145.

Aftab, S. M., Siddiqui, R. H., & Farooqui, M. A. (2018). Strategies to Manage Aquifer Recharge in Balochistan, Pakistan: An Overview. Paper presented at the IOP Conference Series: Materials Science and Engineering.

Akhtar, M. M., Mohammad, A. D., Ehsan, M., Akhtar, R., ur Rehman, J., & Manzoor, Z. (2021). Water resources of Balochistan, Pakistan—a review. J Arabian Journal of Geosciences, 14(4), 289.

Anbarasu, S., Brindha, K., & Elango, L. (2020). Multi-influencing factor method for delineation of groundwater potential zones using remote sensing and GIS techniques in the western part of Perambalur district, southern India. J Earth Science Informatics, 13(2), 317-332.

Arsiso, B. K., Tsidu, G. M., Stoffberg, G. H., & Tadesse, T. (2017). Climate change and population growth impacts on surface water supply and demand of Addis Ababa, Ethiopia. J Climate Risk Management, 18, 21-33.

Bhattacharya, S., Das, S., Das, S., Kalashetty, M., & Warghat, S. R. (2021). An integrated approach for mapping groundwater potential applying geospatial and MIF techniques in the semiarid region. J Environment, development sustainability, 23(1), 495-510.

Díaz-Alcaide, S., & Martínez-Santos, P. (2019). Advances in groundwater potential mapping. J Hydrogeology Journal, 27(7), 2307-2324.

Ehsan, M., Shabbir, H., Al-Quraishi, A. M. F., Al-Ansari, N., Ahmad, Z., Abdelrahman, K., . . . Elbeltagi, A. (2024). Groundwater delineation for sustainable improvement and development aided by GIS, AHP, and MIF techniques. J Applied Water Science, 14(2), 23.

Fagbohun, B. J. (2018). Integrating GIS and multi-influencing factor technique for delineation of potential groundwater recharge zones in parts of Ilesha schist belt, southwestern Nigeria. J Environmental Earth Sciences, 77(3), 69.

Fleming, S. W. (2019). Where the river flows: scientific reflections on Earth's waterways: Princeton University Press.

Hussein, A.-A., Govindu, V., & Nigusse, A. G. M. (2017). Evaluation of groundwater potential using geospatial techniques. J Applied Water Science, 7(5), 2447-2461.

Kakar, Z., Khair, S. M., Khan, M. Z., & Khan, M. A. (2016). Socio-economic impact of water scarcity on the economy of Pishin Lora Basin in Balochistan. J Journal of Applied Emerging Sciences, 5(2), pp90-96.

Khair, S. M., Rasheed, A., & Culas, R. (2021). Improving groundwater management to enhance agriculture and farming livelihoods: Socio-economic analysis of groundwater resource management for Balochistan, Pakistan.

Kodihal, S., & Akhtar, M. (2024). Sustainable groundwater recharge potential zone identification: an AHP-OWA approach integrating future rainfall and land-use projections. J Water Resources Management, 38(3), 1079-1098.

Masood, A., Tariq, M. A. U. R., Hashmi, M. Z. U. R., Waseem, M., Sarwar, M. K., Ali, W., . . . Ng, A. W. (2022). An overview of groundwater monitoring through point-to satellite-based techniques. J Water, 14(4), 565.

Mbamalu, M. N. (2024). Intergrated Remote Sensing and GIS Based Approach for Aquifer zone Detection: A Case Study of Garaku, Nasarawa State. AUST,

Mishra, R. K. (2023). Fresh water availability and its global challenge. J British Journal of Multidisciplinary Advanced Studies, 4(3), 1-78.

Naiman, R. J., & Dudgeon, D. (2011). Global alteration of freshwaters: influences on human and environmental well-being. J Ecological research, 26(5), 865-873.

Nazir, J., Ali, M., Sarwar, A., Khan, S., Rehman, K., Fahim, B., & Iqbal, B. (2024). Delineation and validation of GIS-based groundwater potential zones under arid to semi-arid environment using multi-influence-factors approach. J Geology, Ecology, Landscapes, 1-17.

Owuor, S. O., Butterbach-Bahl, K., Guzha, A. C., Rufino, M. C., Pelster, D. E., Díaz-Pinés, E., & Breuer, L. (2016). Groundwater recharge rates and surface runoff response to land use and land cover changes in semi-arid environments. J Ecological processes, 5(1), 16.

Priyan, K., & region, p. i. t. s.-a. (2021). Issues and challenges of groundwater and surface water management in semi-arid regions. J Groundwater resources development, 1-17.

Saiz-Rubio, V., & Rovira-Más, F. (2020). From smart farming towards agriculture 5.0: A review on crop data management. J Agronomy, 10(2), 207.

Scanlon, B. R., Fakhreddine, S., Rateb, A., de Graaf, I., Famiglietti, J., Gleeson, T., . . . Kolusu, S. R. (2023). Global water resources and the role of groundwater in a resilient water future. J Nature Reviews Earth Environment, 4(2), 87-101.

Seelan, S. K. (2015). Groundwater Targeting Using Remote Sensing. In Remote Sensing Handbook, Volume V (pp. 65-109): CRC Press.

Shah, T. (2014). Groundwater governance and irrigated agriculture: Global Water Partnership (GWP) Stockholm, Sweden.

Shaikh, M., & Birajdar, F. (2024). Advancements in remote sensing and GIS for sustainable groundwater monitoring: applications, challenges, and future directions. J International Journal of Research in Engineering, Science Management, 7(3), 16-24.

Siegel, F. R. (2021). Global Warming and Water 2050: More People, Yes; Less Ice, Yes; More Water, Yes; More Fresh Water, Probably; More Accessible Fresh Water? In The Earth's Human Carrying Capacity: Limitations Assessed, Solutions Proposed (pp. 71-85): Springer.

Suryawanshi, S. L., Singh, P. K., Kothari, M., Singh, M., Yadav, K. K., & Gupta, T. (2023). Spatial and decision-making approaches for identifying groundwater potential zones: a review. J Environmental Earth Sciences, 82(20), 463.

Tiwari, G., & Shukla, J. J. I. J. R. S. G. (2015). A review on remote sensing and GIS techniques in water resource development and management with special reference to groundwater. 4(1), 1-7.

Usman, M., Abbas, A., & Saqib, Z. A. (2016). Conjunctive use of water and its management for enhanced productivity of major crops across tertiary canal irrigation system of Indus Basin in Pakistan. J Pakistan Journal of Agricultural Sciences, 53(1).

Wagner, P. D., Bhallamudi, S. M., Narasimhan, B., Kumar, S., Fohrer, N., & Fiener, P. (2019). Comparing the effects of dynamic versus static representations of land use change in hydrologic impact assessments. J Environmental Modelling Software, 122, 103987.

Westall, F., & Brack, A. (2018). The importance of water for life. J Space Science Reviews, 214(2), 50.