International Journal of Life Science and Agriculture Research
ISSN (Print): 2833-2091, ISSN (Online): 2833-2105
Volume 04 Issue 02 Febraury 2025
DOI: https://doi.org/10.55677/ijlsar/V04I02Y2025-10
Impact Factor: 7.88 , Page No : 122-139

Groundwater potential zones for Agriculture purpose by Using Remote Sensing, GIS and AHP techniques in Northwestern coastal basins at Ras El-Khima, Marsa Matrouh Governorate, Egypt

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ABSTRACT

The primary objective of this study is to demarcate and evaluate GWPZs within semi-arid basins employing a combination of Remote Sensing (RS), Geographic Information System (GIS), and Analytic Hierarchy Process (AHP). A total of eight thematic layers (including geology, geomorphology, lineament density, rainfall land use and land cover, drainage density, soil type and slope) were developed in raster format. Following the AHP methodology and rank assignment, these thematic layers were fused using the raster calculator to generate the GWPZs map. The allocation of weights to each category in all thematic maps was based on their attributes and water potential capacity using the AHP methodology. The examination disclosed that: 50.13% of the studied basins are characterized by low potential, 43.81% are identified as having moderate potential, and 6.06% are recognized as demonstrating high potential.

KEYWORDS: Groundwater Potential Zones, Northwestern Coastal basins, Egypt.

Published Online:
February 22, 2025

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1. INTRODUCTION

Water is the most dynamic natural resource, exerting a significant influence on human life, economic and social development, and the preservation of ecological systems **[1, 2]** Currently, global water resources face pressure primarily due to climatic and human-induced factors. The escalating water demand can be attributed to population growth, rapid urbanization, industrialization, and agricultural practices **[3, 4].** In addition, **[5]** showed that, the challenges associated with groundwater are particularly severe in regions characterized by high population density and economic advancement. In arid and semi-arid areas, the scarcity of water has notably risen due to inadequate surface water availability **[6]**. Research indicates that over 70% of water supply comes from groundwater resources **[7, 8],** which are gradually diminishing at a rate of about 545 km^3 per year due to excessive exploitation **[9].** It has been projected that in arid regions, the majority of groundwater extraction will involve fossil water, posing sustainability concerns for the future **[10]**. The excessive pumping activities have led to a decline in groundwater levels **[11].**

The study area, situated in a semi-arid region within the Mediterranean coastal zone, represents a promising area for agriculture depend on rainfall and extracted groundwater. Presently, within the Mediterranean coastal area, there exists a critical need for the spatial delineation of suitable groundwater potential zones.

The presence and accessibility of groundwater are contingent upon the recharge process influenced by various factors such as physiography, lithological composition, drainage patterns, land use, land cover, as well as climatic variables like precipitation, temperature, and evapotranspiration, in addition to geological features such as fractures and lineaments **[12]**. As a result, the groundwater potential exhibits significant spatial and temporal variations even within the same aquifer. This variability underscores the distinct groundwater potential observed across different locations **[13,14].**

Traditional methods for identifying and mapping groundwater potential zones heavily rely on ground surveys using costly and time-consuming geophysical, geological, and hydrogeological tools. Conversely, geospatial tools offer a swift and cost-efficient means of generating and modeling valuable data in various geoscience domains **[15- 17].** Literature reviews **[18]** and **[13]** indicate that, a variety of techniques employed by researchers for delineating groundwater potential zones and mapping.

Remote sensing and GIS emerge as potent tools for rapid estimation of natural resources, thereby serving as a cost-effective initial step before resorting to detailed and expensive survey methods. Numerous studies have underscored the efficacy of remote sensing and GIS techniques in mapping groundwater potential zones worldwide. In the current research, a combination of Analytical Hierarchy Process (AHP) and GIS methodologies was utilized for delineating groundwater potential zones. Research has amalgamated the application of RS, GIS, and multi-criteria decision analysis to delineate groundwater potential zones, utilizing various hydrogeological, geological, and environmental parameters **[3, 5, 19, 20].** The proposal of the Analytic Hierarchy Process (AHP) by **[21]** was to address intricate decision-making by means of pairwise comparisons. AHP proves to be a valuable approach for prospecting groundwater potential zones (GWPZs) **[7, 22]** as demonstrated by the identification of groundwater potential zones integrating groundwater potential index and water quality index based on AHP in a study by **[23].**

Furthermore, AHP, an internationally recognized technique, utilizes a quantifiable approach **[24, 25]** The assessment of potential groundwater resource zones in rapidly urbanizing regions serves as a versatile decision-making tool for addressing multi-criteria issues. It facilitates problem structuring and ensures that both qualitative and quantitative aspects are considered in the evaluation process. Multi-criteria Decision Making (MCDM) provides a structured, verifiable, transparent, and accurate judgment, proving to be a valuable technique in water resource management based on various studies by **[26].** Although these cost-effective methodologies are limited to small-scale surveys, the complex nature of the Earth's subsurface poses challenges in locating potential groundwater zones. Satellite imagery can be utilized to analyze surface features for identifying the presence or absence of groundwater. In addition, **[27, 28]** mentioned that, AHP logic is used to map inputs to outputs in AHP inference. Each AHP inference system contains a model that translates input data into input membership categories, rules into a set of output characteristics, output characteristics into output membership functions, and output membership functions into a singular output or decision.

The primary objective of this investigation is to identify and outline groundwater zones essential for agricultural water supply for the inhabitants of the study basins, thereby contributing to the sustainable management of water resources within the basins. The methodology employed integrates remote sensing (RS) and GIS with the Analytic Hierarchy Process (AHP). Various thematic layers such as geology, geomorphology, lineament density, land use and land cover, soil type, rainfall, drainage density, and slope were generated. Following the AHP process and rank assignment, the thematic layers were integrated using the raster calculator to produce the map of Groundwater Potential Zones (GWPZs).

2. MATERIALS AND METHODS

Study Area:

The study area includes two basins, namely Umm Ashtan and Umm El-Rakham which are situated at Ras El-Khima city in the northwestern coastal area of Marsa Matrouh Governorate, Egypt. It is bordered by the Mediterranean Sea to the North, coastal zones to the East and West, and the Western Desert to the South. These basins are geographically located between latitudes 31˚ 29` 36,815" and 31˚ 7` 50,232" N and longitudes 26˚ 30` 2,508" and 27˚ 9` 13,273" E as illustrated in Figure 1.

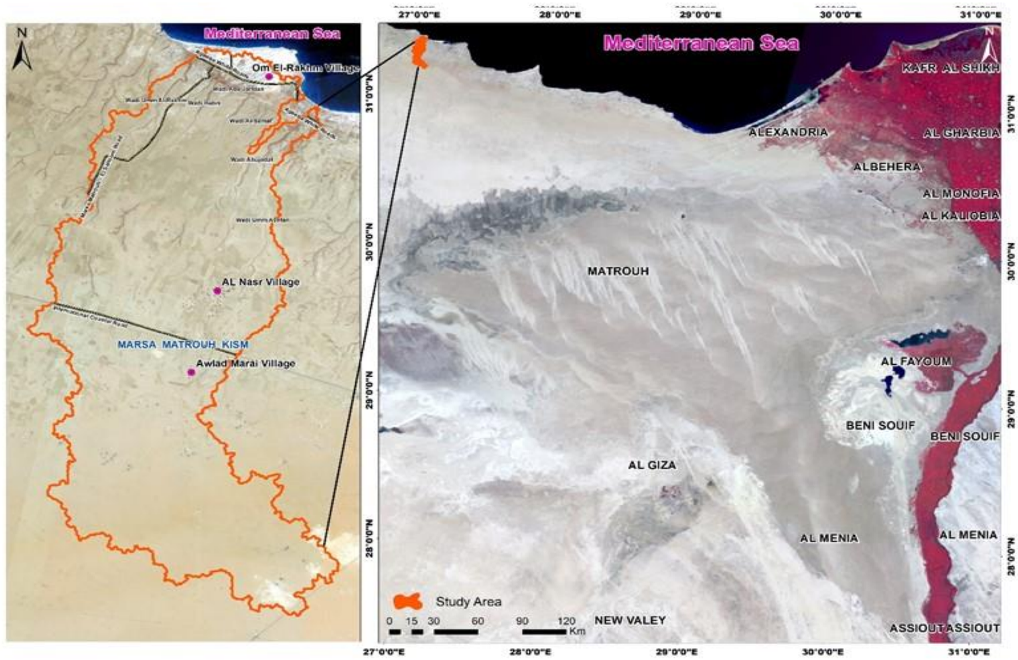

Figure 1. Location map of the study area.

Geospatial methodologies were utilized in the current study to delineate the groundwater potential zones of the study basins through a knowledge-based factor analysis incorporating eight layers of information: geology, geomorphology, land use/land cover (LULC), drainage density, lineaments, rainfall, soil, and slope. The preprocessing of remote sensing data (RS) for the basins were conducted using ERDAS Imagine software **[29]**. The application of Geographic Information Techniques (GIS) was carried out with the utilization of Arc GIS 10.8 software **[30].** The delineation of the basins boundary was achieved using digital elevation model (DEM) a spatial resolution of 12.5 m was downloaded from *http://vertex-retired.daac.asf.alaska.edu,* supported by hydrology tools within GIS software. The preparation of LULC and geomorphology involved the utilization of Sentinel-2 image (10 m Spatial Resolution) was downloaded from *https://browser.dataspace.copernicus.eu*, the acquisition date in June 2022 with 0% of cloud covers, geocoded false color composite satellite data supported by field observations. Visual interpretation techniques were applied to characterize the LULC and geomorphology layers based on satellite data and geomorphology using GIS software. The geology map, sourced from **[31]**, was obtained in published form and subsequently digitized. Soil type was determined by collection of soil profiles from the study area (Figure 2) and mechanical analysis in the lab according to **[32]**. The drainage network, lineament and slope map were prepared from DEM 12.5 m as well as drainage and lineament density maps were generated in GIS platform using density analysis tool. Accordingly, all the thematic layers have been compared with each other in a pair-wise comparison matrix **[5]**.

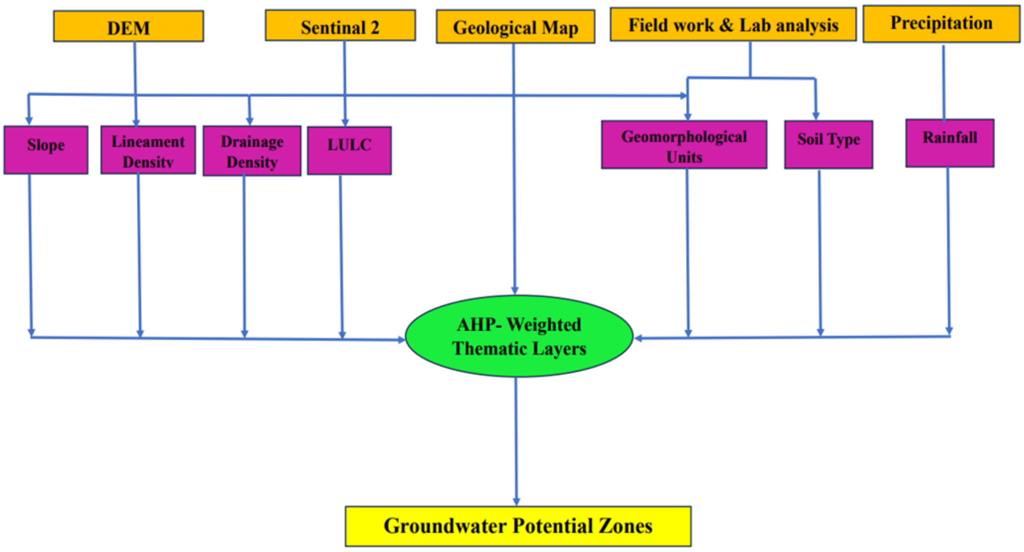

Figure 2. Flowchart of methodology adopted.

All integrated data have effectively delineated the potential groundwater zones using AHP technique (Figure 2). Each thematic layer classes were assigned weightages using AHP and WOA (weighted overlay analysis) methods **[33]**. Thematic layers have been determined to map potential groundwater zones (GWPZ) based on the weighted overlay analysis (WOA). In order to detect a potential groundwater area, and multi-parameters were considered. In the decision-making process for finding groundwater zones, the weights of each parameter were calculated based on their relative importance.

3. RESULTS

The delineation of groundwater potential zones holds paramount importance in the promotion of groundwater recharge. The outcomes have been utilized in the delineation and enhancement of watersheds characterized by deficient aquifer zones. These findings have been derived through the utilization of RS and GIS techniques in conjunction with the AHP. This research emphasizes the significance of natural resource assessment in the identification of appropriate groundwater zones as highlighted by **[34, 35]**. All strata of extraction have been distinctly delineated utilizing digital and visual interpretation methodologies validated by field data. The study has incorporated eight essential thematic layers for the mapping of suitable groundwater zones, where these layers have been ranked according to the hierarchical analytical process following the saaty scale.

3.1. Geology:

The northern section of the Western Desert of Egypt is characterized by a nearly flat plain with minimal exceptions. As described by **[36]**, this part of the Western Desert consists of uncomplicated surface structures covered by gently inclined Tertiary strata that are widespread and exhibit reasonable lithological consistency. Surface structures in the area are mainly delineated by a few major fault lines, with minor folds displaying gentle dips, while subsurface structures are intricate, indicating significant tectonic activities. Various authors, including **[37- 38]** have discussed the geology of the northern Western Desert. A substantial portion of the northern

Western Desert is overlain by a thin layer of Miocene rocks that unconformably overlie older rock layers. Towards the east, lower Miocene sediments lie above basalt flows or 'continental' Oligocene sediments, suggesting a period of non-deposition and erosion. To the west, the unconformity truncates upper Eocene shales and marls. Rock formations in the study area, stretching from Marsa Matruh governorate to El-Gargoub Seaport, range from Middle Miocene carbonates (Marmarica Formation) to Quaternary carbonates and clastics. In Marsa Matruh, it is reported that Miocene sediments rest atop Turonian dolomites with a prominent angular unconformity. The top of the Miocene interval is characterized by an unconformity on which the gently sloping Pliocene sediments of the coast lie. The Middle Miocene rock unit, represented by the Marmarica Formation, has a wide spatial distribution in the study area compared to other rock units **[31]** (**Figure 3)**. Generally, the Quaternary sediments of the deserts of Egypt are varied and complex. In the deserts, however, the Quaternary sediments are thin and incomplete **[37]**. Quaternary coastal plain of Northwest Egypt is bordered to the south and to the west by the outcropping Middle Miocene Marmarica Limestone which forms a tableland **[39]**.

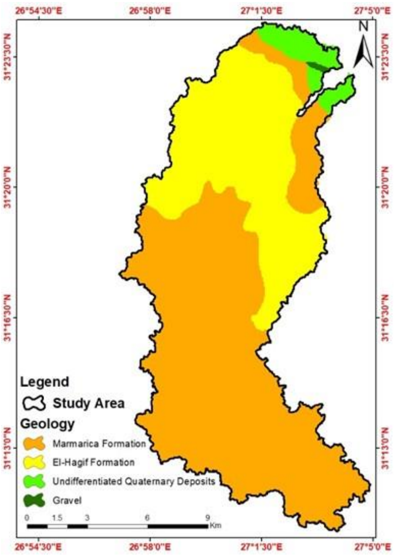

Figure 3. Geological units map, modified after CONCO, 1989 in the study area.

3.2. Geomorphology:

The mapping of geomorphology is essential for identifying suitable groundwater zones, a process facilitated by the utilization of satellite data to recognize various landforms. The characteristics of geomorphology are closely linked to the structural assessment of geological rock formations. Therefore, geomorphological mapping significantly contributes to the demarcation of groundwater zones and the formulation of strategies for soil and water conservation **[40]**. Geomorphology, together with information on water, soil and vegetation, is a major input when planning various development activities. On the other hand, in any area, the geomorphology of the land depends on the structural development of geological formations and reflects the different landforms and their structural characteristics **[41].**

Geomorphological units map was created by combining satellite images, geological maps and digital elevation models (DEM) which improve the classification of landforms. All available information is integrated using GIS **[42]**. The study area encompasses eight distinct landform units, namely coastal plain, sloping area, escarpment, coarse valley inner, coarse valley outer, low piedmont, moderately high piedmont, and high piedmont (**Figure 4**).

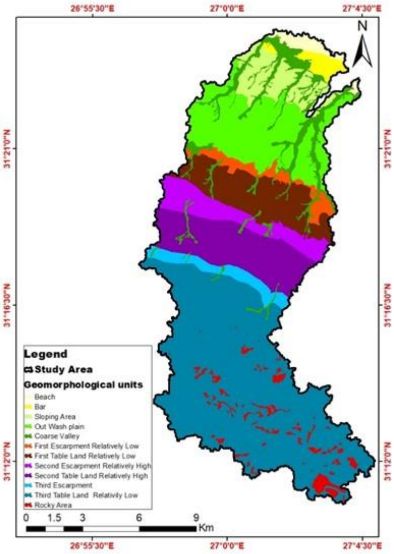

Figure 4. Geomorphological units map in the study area

3.3. Rainfall:

Rainfall serves as the primary hydrological cycle water source and exerts the most significant influence on the groundwater within a specific region **[5]**. In this study, rainfall data for the year 2022 were used. It was downloaded from *https://power.larc.nasa.gov/data-access-viewer/.* The annual precipitation levels in the study area vary between 166 mm and 266.6 mm (**Figure 5**). Through the utilization of the Inverse Distance Weighting (IDW) interpolation technique in Arc GIS, a spatial distribution map illustrating rainfall patterns was constructed.

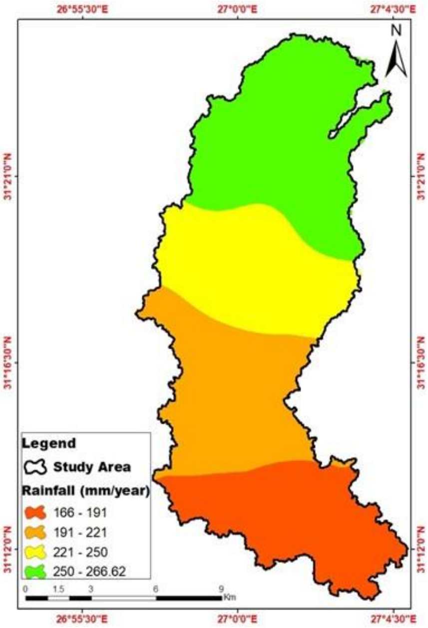

Figure 5. Rainfall (mm/year) map in the study area.

3.4. Drainage density (Dd):

Drainage density is the total length of all the rivers in the river basin divided by the total area of the drainage basin and is generated using the DEM data in the Arc GIS software **[41]**. Drainage density plays a crucial role in determining the groundwater potential zones along drainage lines and in agricultural fields. When the drainage level is high and water penetration into the ground is low, water runoff tends to be high. Conversely, regions with low drainage density experience lower surface water runoff, allowing for a higher infiltration of surface water into the ground **[38]** Therefore, a high drainage density represents a low infiltration rate and therefore does not contribute much on the groundwater potential, while a low drainage density represents a high infiltration rate and therefore contributes significantly to the groundwater potential **[5]** (**Figure 6**).

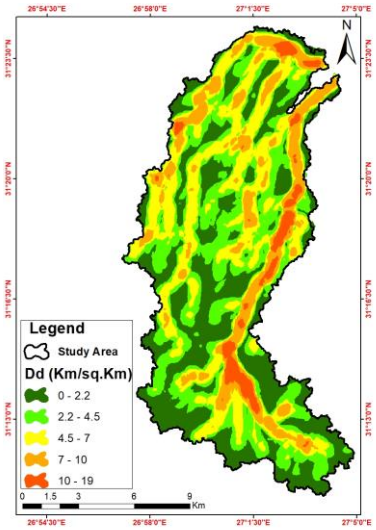

Figure 6. Drainage density map in the study area

3.5. Land use / land cover (LU/LC):

The land use / land cover maps were derived through utilizing supervised classification techniques of Sentinel-2 satellite data within ERDAS software in conjunction with ground truth data. In comparison to alternative software, the remote sensing software provides precise foundational data on land use classes, facilitating the creation of comprehensive land-use maps **[40]**. From LULC map of an area, it is possible to assume important information on soil moisture, groundwater requirements, infiltration rate, and surface water **[44]**. Also, LULC map is the main factor controlling the groundwater storage process **[45]**.

The delineation of study basins into six distinct LU/LC categories is clearly outlined (**Figure. 7**). The land use classes within the semi-arid region exhibit a high degree of variability due to the influences of climate change and the limited availability of water resources **[46]**.

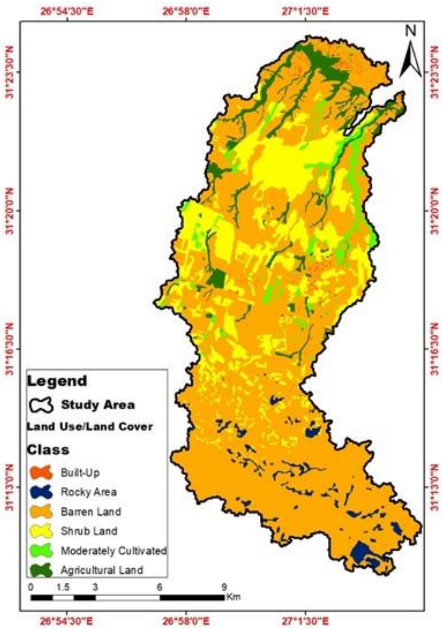

Figure 7. Land Use and Land Cover map in the study area.

3.6. Lineaments density (LD):

The lineaments are spread over a wide range of the earth's surface and take the form of straight or almost straight landforms **[47]**. Also, reflects the general appearance of cracks or fractures underground **[6]**. Therefore, facilitates the percolation of water into the ground and thus plays an important role in the movement and storage of groundwater **[48]**. The presence of a high density of lineaments can prove to be advantageous in facilitating the creation of aquifer zones within regions characterized by hard calcareous rock, as observed in the basins under study. Consequently, the density of lineaments emerges as a key factor influencing the strategic planning and sustainable development of groundwater resources within the examined area.

Through the creation of lineament map using satellite imagery and digital elevation models (DEM) alongside field data references within the Arc GIS software, a comprehensive understanding of the geological landscape is achieved, as illustrated in **Figure 8**.

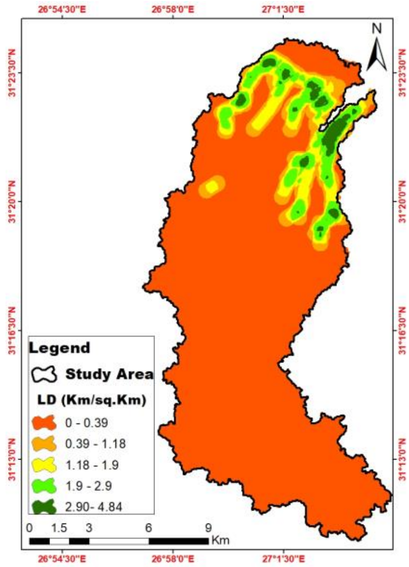

Figure 8. Lineaments Density map in the study area.

3.7. Slope:

Slope is a critical parameter in determining groundwater potential as it is inversely related to the infiltration rate **[49]**. The slope map serves as a crucial factor in groundwater management, as well as in the planning of soil and water conservation sites, particularly in areas characterized by undulating topography and rugged rock terrain **[50]**. It has the capacity to retain and channel water into the soil, thereby enhancing groundwater retention, while steep slopes prolong runoff by reducing the infiltration of surface water into the ground **[38]**. Generally, Flat areas have high infiltration rates and low surface runoff and are therefore highly correlated with groundwater potential zone **[51]**. Conversely, steeply sloped areas have high surface runoff and low infiltration rates and are therefore considered to have very low groundwater potential zone **[52]**. The surface slope in the study area was categorized into distinct classes on the slope map (**Figure 9**).

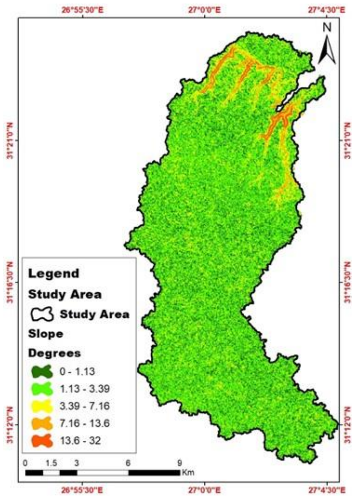

Figure 9. Slope map in the study area.

3.8. Soil:

Soil plays a crucial role in the demarcation of zones with high groundwater potential **[5]**. The infiltration of groundwater and surface water into the soil is contingent upon the soil's porosity and permeability. Consequently, the assessment and identification of ground-water quantities, along with appropriate recharge locations. The movement of water infiltration differs across the soil types, leading to the assignment of weights based on their respective properties. Various soil types present in the study area include sandy clay loamy, sandy loam and loamy sand (**Figure 10**).

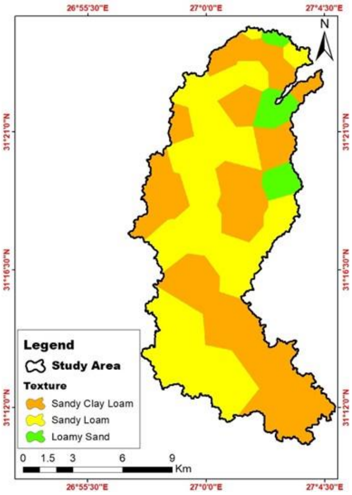

Figure 10. Soil type (A) and its ground water potential rating (B) in the study area

3.9. Weight Calculation Using Analytical hierarchical process (AHP):

The AHP is a Multi-Criteria Decision-Making (MCDM) method advanced and widely used to analyze spatial decision problems in natural resource management, including groundwater issues **[54,55]**. In addition, AHP method is used to evaluate the weight of various layers **[12]**. The first step is the construction of a Pairwise Comparison Matrix (PCM) using Saaty's scale (1–9) of relative importance by **[56]** (Table 1). After comparison each layer based on their relative importance, a PCM for eight variables was constructed (Table 2). The second step of this method is to calculate the normalized weights to reduce the associated subjectivity. A sum of the values in each column was shown in Table 3. Thereafter, each of the column values was divided by the sum of the columns to generate the Normalized Pairwise Comparison Matrix (NPCM) **[4,11]**. The normalized weight (N_{wt}) of each variable was obtained by averaging all the values of the corresponding row in the NPCM (Table 3). The sum of all normalized weights is always 1.

Table 1. Saaty's scale of relative importance.

Scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one above other	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored, and its dominance
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

Table 2. Pairwise Comparison Matrix of eight variables for AHP method.

Factors	Geol-ogy	Geomorphology Units	Rainfall	Lineament density	Slope	LULC	Drainage density	Soil type
Geology	1	2	3	2	2	4	4	6
Geomorphology	1/2	1	2	2	3	5	2	4
Rainfall	1/3	½	1	3	2	4	5	2
Lineament density	1/2	½	1/3	1	3	2	2	4
Slope	1/2	1/3	1/2	1/3	1	2	3	2
LULC	1/4	1/5	1/4	1/2	1/2	1	3	2
Drainage density	1/4	½	1/5	1/2	1/3	1/3	1	3
Soil type	1/6	¼	1/2	1/4	1/2	1/2	1/3	1
Sum	3.50	5.28	7.78	9.58	12.33	18.83	20.33	24.00

Table 3. Normalized Pairwise Comparison Matrix.

Factors	Geol-ogy	Geomorphol-ogy Units	Rainfall	Lineament density	Slope	LULC	Drainage density	Soil type
Geology	0.2857	0.3785	0.3854	0.2087	0.1622	0.2124	0.1967	0.2500
Geomorphology	0.1429	0.1893	0.2570	0.2087	0.2432	0.2655	0.0984	0.1667
Rainfall	0.0952	0.0946	0.1285	0.3130	0.1622	0.2124	0.2459	0.0833
Lineament density	0.1429	0.0946	0.0428	0.1043	0.2432	0.1062	0.0984	0.1667
Slope	0.1429	0.0631	0.0642	0.0348	0.0811	0.1062	0.1475	0.0833
LULC	0.0714	0.0379	0.0321	0.0522	0.0405	0.0531	0.1475	0.0833
Drainage density	0.0714	0.0946	0.0257	0.0522	0.0270	0.0177	0.0492	0.1250
Soil type	0.0476	0.0473	0.0642	0.0261	0.0405	0.0265	0.0164	0.0417

3.10. Delineating the groundwater potential zone:

The groundwater potential zone was delineated through the utilization of Analytical Hierarchy Process (AHP), remote sensing, and Geographic Information System (GIS) methodologies. Integration of various layers including geology, geomorphology, rainfall, lineament density, slope, soil, and land use was carried out. **[57-59]** showed that, delimitation of potential groundwater zones was achieved by employing thematic layers, weighted overlay analysis, and Analytical Hierarchical Process (AHP) techniques. Subsequently, classification of different groundwater potential zones was conducted based on thematic layers to facilitate groundwater planning and development **[40]**.

According to the assigned ranking and weighting of the chosen thematic layers based on their water storage capacity, a re-classification was conducted (Table 4). Besides **[60]** reported that, the cumulative weighting percentages utilized for geology, geomorphology, soil, drainage density, line density, slope, and land use/ land cover were integrated into a Weight of Evidence Analysis (WOA) to generate the Groundwater Potential Zone (GWPZ) map.

Table 4. Classes, rating and criteria weight of different parameters for groundwater potential zone.

parameter	Class	Rating	Criteria weight (%)
Geology	Marmarica Formation	2	26
	El-Hagif Formation	3	
	Undifferentiated Quaternary Deposits.	4	
	Gravel	4	
Geomorpho-logical units	Rocky Area	1	26
	Third Escarpment	1	
	First Escarpment Relatively Low	2	
	Second Escarpment Relatively High	2	
	Second Table Relatively High	2	
	Third Table Relatively Low	2	
	Bar	3	

	Beach	3	
	First Table Relatively Low	3	
	Sloping Area	3	
	Out Wash plain	4	
	Coarse Valley	5	
Rainfall (mm/Year)	166 – 191	1	17
	191 – 221	2	
	221 – 250	3	
	250 – 266.62	4	
Lineament density (Km/ Km2)	0 – 0.39	1	12
	0.39 – 1.9	2	
	1.9 – 1.18	3	
	1.9 – 2.9	4	
	2.90 – 4.84	5	
Slope Degrees	0 – 1.13	5	9
	1.14 – 3.39	4	
	3.39 – 7.16	3	
	7.16 – 13.6	2	
	13.7 - 32	1	
Land use/Land cover (LULC)	Rocky Area	1	6
	Built Up	1	
	Barren Land	2	
	Shrubland	3	
	Moderately Cultivated	4	
	Agriculture Land	5	

4. DISCUSSION

4.1. Geology:

Geology plays a crucial role in the identification of potential groundwater zones and the analysis of its occurrence. The study area is facing numerous challenges related to groundwater and drought, especially it located in semi-arid regions. Weight assignment for groundwater classes was carried out according to the AHP method. The final geological map was utilized to comprehend the flow of aquifers and the composition of rocks **[40]**.

The restructuring of the region's classification according to geological formations reveals that 62.8 % exhibit low groundwater potential, 32.6 % display moderate potential, and 4.5 % demonstrate high potential (**Figure 11**). Nevertheless, this categorization pertains solely to the initial intrinsic capability of the formations and does not consider the potential resulting from subsequent processes. To address these constraints, alternative thematic layers were employed to evaluate the groundwater potential.

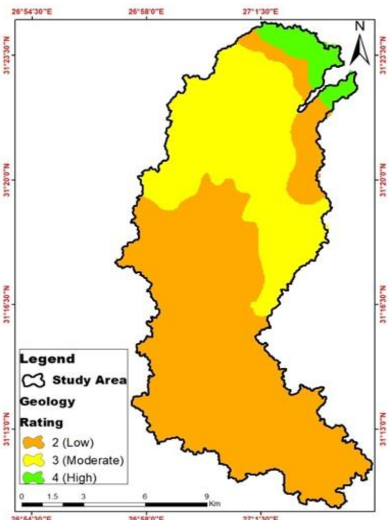

Figure 11. Ground water potential rating map according to Geology.

4.2. Geomorphology:

The mapping of geomorphology is essential for identifying suitable groundwater zones, a process facilitated by the utilization of satellite data to recognize various landforms. The characteristics of geomorphology are closely linked to the structural assessment of geological rock formations. Therefore, geomorphological mapping significantly contributes to the demarcation of groundwater zones and the formulation of strategies for soil and water conservation **[40]**. Areas with land features that facilitate the flow of storm water into the underground aquifers are perceived as possessing favorable groundwater potential. This particular aspect of geomorphological traits has prompted the segmentation of a specific area into categories of high, moderate, and low groundwater potential. The present investigation reveals that 6.8 % of the analyzed area has very high groundwater potential, 13.6 % exhibits high potential, 15.9 % display moderate potential, while 58.8 possess low potential and the remaining 4.9 % manifest very low potential, as depicted in (**Figure 12**).

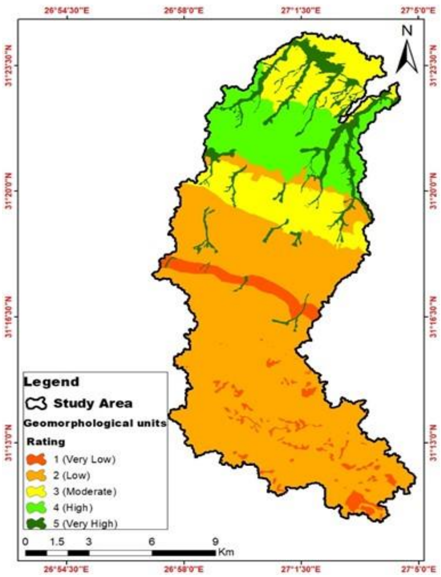

Figure 12. Ground water potential rating map according to Geomorphological units.

4.3. Rainfall:

Categorization of rainfall into four distinct groups has been conducted based on the maximum and minimum values, namely Very Low groundwater potential (21.7 %), Low potential (24.1 %), Moderate potential (22.4%) and High potential (31.8) (**Figure 13**). Infiltration processes are contingent upon the intensity and duration of rainfall events. Specifically, rainfall characterized by high intensity and short duration tends to inhibit infiltration while promoting surface runoff. Conversely, rainfall events with low intensity and prolonged duration facilitate increased infiltration relative to runoff. Weight assignments are notably higher for substantial rainfall occurrences and vice versa.

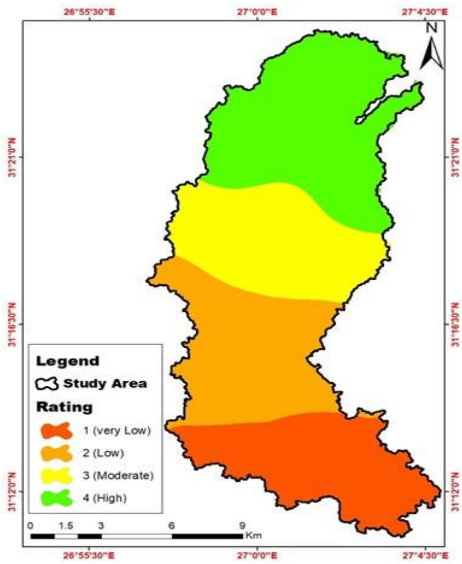

Figure 13. Ground water potential rating map according to Rainfall (mm/year).

4.4. Drainage density (Dd):

The study area was partitioned into different zones based on the drainage density (Figure 6 A), with 31.2 % of the zones exhibiting very high potential, 27.4 display high potential, 24.3% showing moderate potential, 13.3 have low potential and 3.8 % indicating very low potential (**Figure 14**).

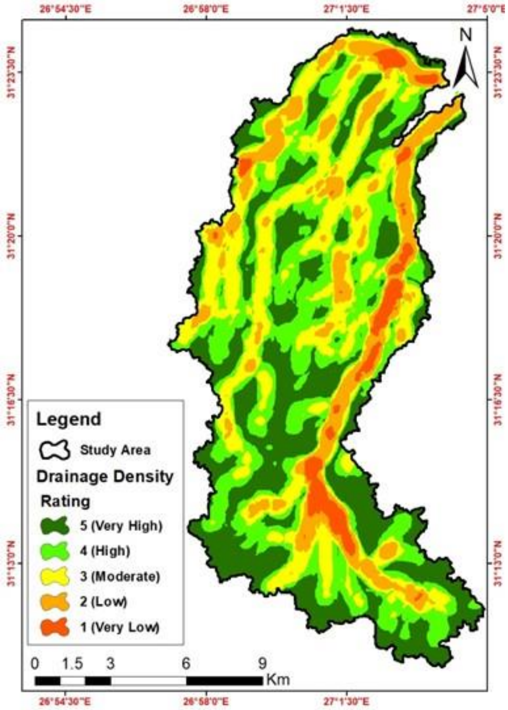

Figure 14. Ground water potential rating map according to the Drainage density.

4.5. Land use / land cover (LU/LC):

The land use / land cover map is the main factor controlling the groundwater storage process **[45]**. The delineation of study basins into six distinct LU/LC categories is clearly outlined. The division of the study area into different categories based on LU/LC revealed that 2.8 % of the area exhibits very low potential, 68.9 % have low potential, 18.9 % shows moderate potential, 3.4 % exert high potential and 6 % displays very high potential zones, as illustrated in **Figure 15**.

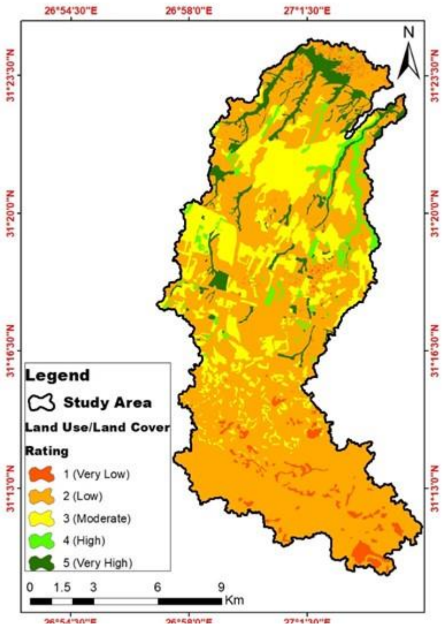

Figure 15. Ground water potential rating map according to Land Use and Land Cover.

4.6. Lineaments Density (LD):

The lineaments are spread over a wide range of the earth's surface and take the form of straight or almost straight landforms [47]. Also, reflects the general appearance of cracks or fractures underground [6]. Therefore, facilitates the percolation of water into the ground and thus plays an important role in the movement and storage of groundwater [48]. Through the creation of lineament map using satellite imagery and digital elevation models (DEM) alongside field data references within the Arc GIS software, a comprehensive understanding of the geological landscape. The division of the study area into different categories based on lineament density revealed that 82.1 % of the area exhibits very low potential, 5.6 % have low potential, 5.4 % shows moderate potential, 5.1 % exert high potential and 1.9 % dis-plays very high potential zones, as illustrated in **Figure 16**.

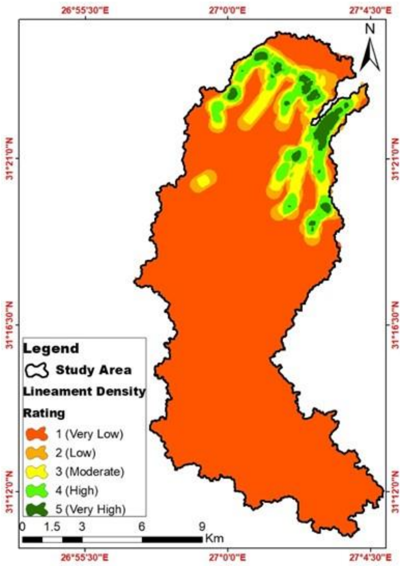

Figure 16. Ground water potential rating map according to Lineaments Density.

4.7. Slope:

Slope is a critical parameter in determining groundwater potential as it is inversely related to the infiltration rate **[49]**. The slope map serves as a crucial factor in groundwater management, as well as in the planning of soil and water conservation sites, particularly in areas characterized by undulating topography and rugged rock terrain **[50]**.

The categorization of the study site according to slope factor revealed that 26.9% exhibited very high potential, 58.8% shows high potential, 11.5% displays moderate potential with a smaller percentage classified as low (2.0%) and a minimal proportion as very low (0.8%) potential (**Figure 17**).

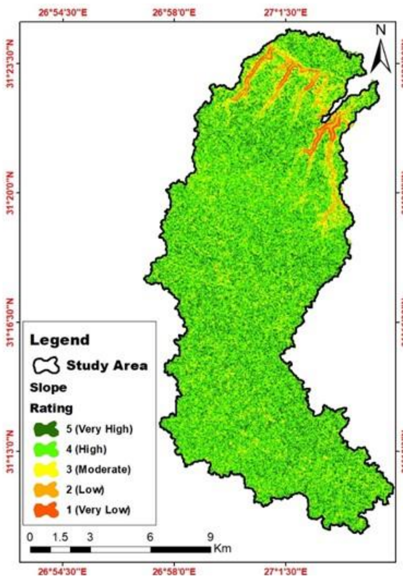

Figure 17. Ground water potential rating map according to Slope.

4.8. Soil:

Soil plays a crucial role in the demarcation of zones with high groundwater potential **[5]**. The study reveals that loamy sand exhibits high permeability, while sandy loam shows a moderate to medium level of permeability. Sandy clay loam displays a moderate to high level. The permeability of coarse sandy loam is categorized as medium **[53]**. The classification of the study area into 47.6% low potential, 46.9% moderate potential, and 5.5% high potential categories was determined based on the infiltration capabilities of these soils (**Figure 18**).

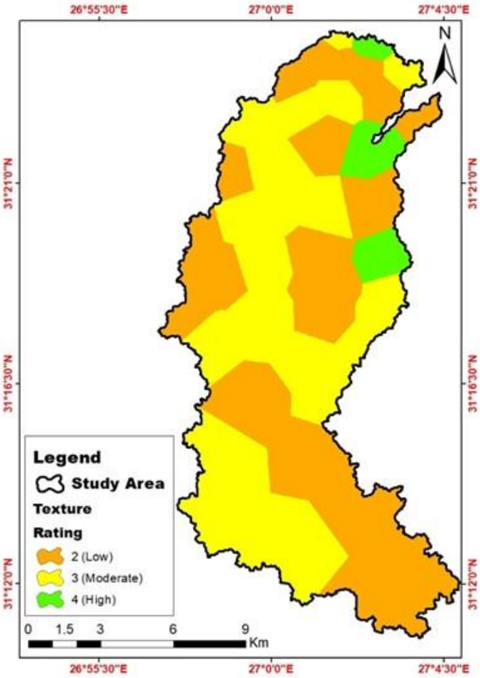

Figure 18. Ground water potential rating map according to Soil.

4.9. Delineating the groundwater potential zone:

The groundwater potential zone was delineated through the utilization of Analytical Hierarchy Process (AHP), remote sensing, and Geographic Information System (GIS) methodologies.

The delineation resulted in the categorization of groundwater potential zones into three classes: 50.13 % having low potential, 43.81 % exhibiting moderate potential, and 6.06 % demonstrating high potential (**Table 5 and Figure 19**). This illustration demonstrates the presence of a significant groundwater potential zone prominently distributed across the north of the study area due to factors such as geology, geomorphology, and rainfed areas with high infiltration capacity. Specifically, the significance of soil types and slope values in influencing groundwater development in semi-arid regions is highlighted. Moreover, the interaction between drainage density and lineament density also contributes to enhancing the infiltration capacity of the groundwater system.

Table 5. Categorizes, areas and percent of groundwater potential zones in the study area.

Class	Area (Km2)	Area (Feddan)	%
Low	88.27	21016.4	50.13
Moderate	77.14	18367.7	43.81
High	10.68	2542.8	6.06
Total	176.1	41927.0	100.000

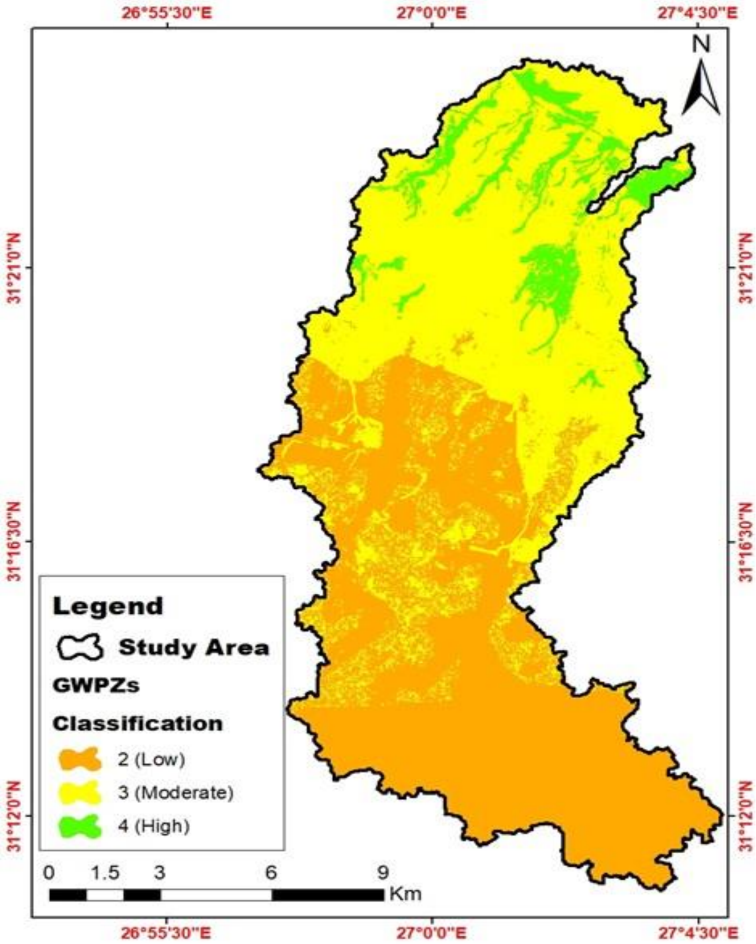

Figure 19. Groundwater potential zone of the study area

5. CONCLUSIONS

Field studies and satellite imagery is utilized to provide detailed information for the classification of various geological categories, linear features, hydro geomorphological elements, LULC, drainage density, soil types and slope. These geographical features serve as valuable indicators of groundwater levels within the basin. The application of Analytical Hierarchy Process (AHP), Geographic Information System (GIS), and remote sensing (RS) has yielded significant outcomes for basin development. The integration of AHP with GIS has facilitated the establishment of an efficient framework for spatial data management and weighted overlay analysis. By combining and analyzing various thematic layers, suitable groundwater zones can be effectively identified. The study recommends leveraging GIS technology alongside remote sensing data to optimize groundwater investigations, reducing costs, time, and human resources while enhancing accuracy. The insights gained can benefit groundwater management, agricultural practices, and irrigation strategies in semi-arid regions. The study area encompasses a percentage of the basins falling under each respective potential zone. The groundwater potential map is categorized into three classes: high, moderate, and low potential zones.

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