Delineating Groundwater Potential Zones in Parts of North Central Nigeria, Using Geographical Information System (GIS) and Analytical Hierarchical Process (AHP) Techniques

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ABSTRACT

This project delineates groundwater potential zones in Kaiama, North-Central Nigeria, using Geographical Information System (GIS) and Analytical Hierarchy Process (AHP) techniques. Eight critical thematic layers, including geomorphology, lineament density, geology, slope, land use land cover (LULC), drainage density, elevation, and aspect, were integrated using the AHP method. The process was integrated into the GIS environment to generate a comprehensive groundwater potential map. The groundwater potential map obtained was classified as very high, high, average, low, and very low groundwater potential zones. The result showed that 15 %, 6 %, 13 %, 21 %, and 44 % of the study area fall under a very high, high, average, low, and very low groundwater potential zone, respectively. Vertical Electrical Sounding (VES) data from 20 locations across the study area were used to validate the accuracy of the delineated groundwater potential zones. The validation process employed Receiver Operating Characteristic (ROC) analysis, comparing the VES data with the generated groundwater potential map. The Area Under the Curve (AUC) was calculated to assess the model's predictive accuracy yielding a moderate value of 0.60. The findings from this research showed that the integration of GIS, Remote sensing (RS), and, the multi-criteria decision-making approach (MCDA) based on (AHP) techniques provide a reasonable framework for groundwater potential delineation and exploration.

Keywords: Remote Sensing, MCDA, Geomorphology, Lineament density, ROC, AUC

INTRODUCTION

Groundwater accounts for approximately one-third of global freshwater abstractions (Das *et al.* 2019). It is a crucial natural resource for economic and social development in regions with scarce water supplies (Kordestani *et al.* 2019). All economic activities rely heavily on groundwater, either directly or indirectly. However, factors such as underlying geology, chemical weathering intensity, recharge efficiency, groundwater level, and surface element origins significantly impact groundwater resources, whereas surface water is more susceptible to pollution (Yıldırım 2021). Due to its proximity to the surface, surface water naturally has a lower mineral composition than groundwater, making it more vulnerable to contamination from human activities (Gbosh *et al.* 2020). Moreover, building surface water extraction infrastructure for various uses is generally more expensive and requires a larger area compared to groundwater extraction sites.

Identifying and exploring groundwater in a given region can be challenging due to its concealed nature, making detection difficult. Traditional methods of groundwater exploration, such as drilling and hydrogeological, geological, and geophysical strategies, are not only expensive and time-consuming (Jha *et al.* 2010) but also may overlook various factors influencing groundwater movement and occurrence (Oh *et al.* 2011). To address these limitations, researchers have employed various techniques, including logistic regression (Rizeei *et al.* 2018), weight of evidence (Rahmati *et al.* 2016), fuzzy logic (Halder *et al.* 2020), machine learning techniques like boosted regression tree (Prasad *et al.* 2020), random forest (Norouzi and Moghaddam 2020), support vector machine (Pourghasemi *et al.* 2020), multivariate adaptive regression splines (Golkarian *et al.* 2018), frequency ratio (Das and Pardeshi, 2018), index of entropy (Yariyan *et al.* 2021), maximum entropy (Jaafarzadeh *et al.* 2021), certainty factor models (Hou *et al.* 2017), artificial neural network model (Lee *et al.* 2012), decision tree (Jeihouni *et al.* 2019), Shannon's entropy (Khoshtinat *et al.* 2019), and Fisher's linear discriminant function (Chen *et al.* 2019). However, these methods rely on bivariate and multivariate statistical techniques, which have limitations in making assumptions before investigations and the sensitivity of results (Thapa *et al.* 2017).

Recently, the integrated use of remote sensing (RS) and geographical information systems (GIS) for groundwater exploration has gained popularity due to its cost-effectiveness, efficiency, and time-saving benefits (Arulbalaji *et al.* 2019). Geospatial techniques have been extensively used worldwide to delineate groundwater potential zones, such as in Southwest Asia (Abijith *et al.* 2020), Africa (Ahmad *et al.* 2020), and the Arabian Peninsula (Mohammadi-Behzad *et al.* 2019). The analytical hierarchy process (AHP) is a widely used multi-criteria decision-making (MCDM) model for identifying potential groundwater zones, offering a simple, easy, cost-effective, transparent, and reliable approach (Dar *et al.* 2020). Integrating AHP and GIS provides a cost-effective method for spatial data management (Shekhar and Pandey 2014). Over the past few decades, researchers have utilized the AHP technique to weigh various thematic layers and identify potential groundwater zones, providing more accurate results and requiring less computation time than traditional field methods (Zolekar and Bhagat 2015).

This study evaluates the potential zones for groundwater development (GWPZ) in Kiama, North Central Nigeria. To achieve this, various parameters were comprehensively analyzed to identify and assess areas with potential for groundwater availability. The research aims to bridge the knowledge gap in understanding the groundwater potential of this region, which has not been previously investigated. By employing a multi-criteria decision analysis (MCDA) approach combining the Analytic Hierarchy Process (AHP), Remote Sensing (RS), and Geographical Information Systems (GIS), this study seeks to delineate distinct areas with varying groundwater potentials. The findings of this research will provide valuable insights for future initiatives in sustainable groundwater management, ensuring the optimal utilization of this vital resource.

Study Area

Kaiama, the provincial capital of Kaiama Local Government Area, is located in the northwestern part of Kwara State, Nigeria within the Federal Survey map of Nigeria Sheet 158, Kaiama SE, the area spans approximately 770 km^2 (Figure 1). Defined by Latitude N09°30'00" to N09°45'00" and Longitude E03°45'00" to E04°00'00", Kaiama is a border town, approximately 60 km from the international boundary with Benin Republic. Kaiama is bounded by Niger State to the north, Oyo State to the south, and Baruten LGA of Kwara State to the west.

The study area is characterized by a temperate climate with two distinct seasons: the rainy and the dry season. The rainy season starts from May to September and is marked by cool temperatures ranging from 20°C to 35°C. In contrast, the dry season which spans from October to April, is characterized by hot and dry conditions. The study area's terrain is characterized by moderate relief in parts, with flood plains in others, relative to the surrounding hills. The major rock exposures are hills, with the highest elevation reaching 419 m above sea level and the lowest point being 289 m above sea level. The drainage system in the area is characterized by streams and rivers that flow from the northern end towards the southern end. However, most of these rivers and streams dried up during the mapping exercise, indicating rainfall as the main source of recharge.

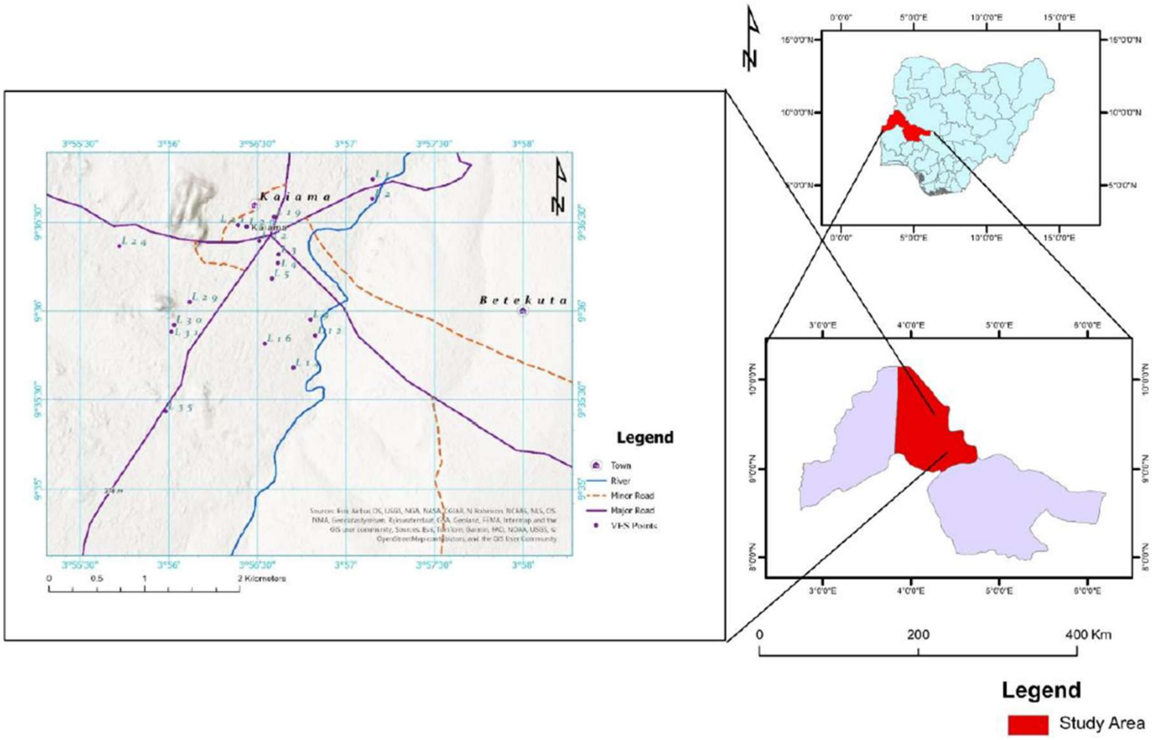

Figure 1: Location map of the Study area

MATERIAL AND METHOD

Various steps adopted in delineating groundwater potential zones are shown on the flowchart (Figure 2).

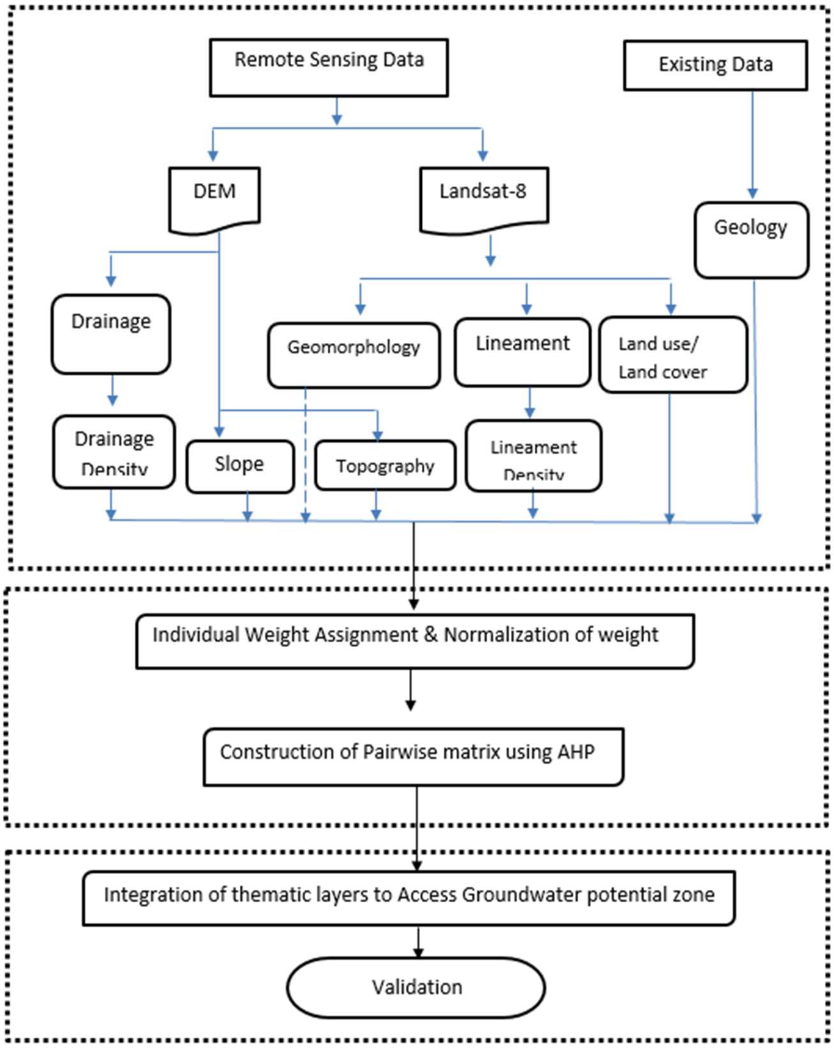

Figure 2: Flow chart of the methodology used for delineating groundwater potential zones.

Preparation of thematic layers

Various thematic maps were used in delineating groundwater potential zones based on their criteria and different factors, eight thematic maps (Geology, lineament density, drainage density, geomorphology, slope, land use/land cover, elevation, and aspect) were used to generate the groundwater potential map in a GIS system (ArcGIS 10.5). The geology and lineaments maps of the research area were obtained from the Nigerian Geological Survey Agency from which thematic layer maps were produced employing ArcGIS 10.5. Subsequently, the lineament density layer was produced. The geomorphology, slope, elevation, and aspect maps were created using the Digital Elevation Model (DEM) of the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) with a 30 m spatial resolution. ASTER-DEM (https://search.earthdata.nasa.gov/search) was adopted to prepare the drainage map, which was then processed to create the drainage density map. The Land use/Land cover map of the study area was generated from a Landsat-8.

All the thematic layers were then categorized into four different maps which include:

1. Geological Maps: Geological maps provide information about the lithology, structure, and hydrogeological characteristics of the subsurface. They help identify aquifer types, lithological boundaries, and geological controls on groundwater occurrence.
2. Topographic Maps: Topographic maps provide elevation data, slope and its gradients (aspect), and drainage patterns, which influence groundwater flow and storage. Digital Elevation Models (DEMs) derived from topographic data are used for terrain analysis and hydrological modeling.
3. Remote Sensing Imagery: Satellite imagery and aerial photographs are utilized for land cover mapping, surface water delineation, and land use classification. Remote sensing data provide spatial information on vegetation cover, surface characteristics, and land surface temperature, influencing groundwater recharge and evapotranspiration.
4. Hydrological Parameters: Hydrological parameters such as rainfall, evapotranspiration, soil properties, and land use/land cover are essential for estimating groundwater recharge rates, infiltration capacities, and groundwater availability.

Assignment and Normalization of weight using AHP

In an integrated analysis, the most critical step is the weighting of each class because the final result is dependent on this step (Muralitharan and Palanivel 2015). This study uses the AHP-based Multi-Criteria Decision Analysis technique to assign weights. It is used as a decision-making technique to determine the final weights assigned to various thematic layers and their associated features (Sener *et al.* 2005). For the past few decades, the MCDM-AHP method has been widely used in multiple studies, including groundwater potential maps. Tomas Saaty developed the AHP in 1980 (Saaty 1980) as an efficient tool for organizing and resolving complex decision-making in groundwater. The AHP model has four stages: weight assignment, pairwise comparison matrix, weight normalization, and consistency assessment (Benjmel *et al.* 2020).

This technique begins by creating a decision hierarchy and then identifying criteria and sub-criteria depending on their influences on groundwater potential. The benefit of hierarchy is that it enables us to focus judgment on individual properties, which is critical for making strong decisions (Murmu *et al.* 2019). All themes' relative importance values and associated characteristics were determined using a standard Saaty's 1–9 scale (Saaty 1980) (Table 1).

Table 1: Saaty's 1–9 scale of relative importance.

Scale	1	2	3	4	5	6	7	8	9
Importanc e	Equal Importanc e	Wea k	Moderate Importanc e	Moderat e plus	Strong importanc e	Stron g plus	Very strong importanc e	Very, very stron g	Extreme importanc e

All eight thematic layers were assigned weights as per groundwater potential impact, expert advice, field experience, and literature review. Geomorphology is assigned the highest weight, which is assumed to have a more significant effect on groundwater (Table 2). In contrast, the slope aspect is assigned the lowest weight, which has less influence on groundwater (Shao *et al.* 2020).

A pairwise comparison matrix is computed after giving relative weights to each factor. All thematic layers were compared during the pairwise comparison matrix (Table 2).

Table 2: Pairwise comparison matrix for all factors developed for AHP-based groundwater potential zoning

Factors	Geomorphology	Lineament Density	Geology	Slope	LULC	Drainage Density	Elevation	Aspect
Geomorphology	1	9/8	9/7	9/6	9/5	9/4	9/2	9
Lineament Density	8/9	1	8/7	8/6	8/5	8/4	8/2	8
Geology	7/9	7/8	1	7/6	7/5	7/4	7/2	7
Slope	6/9	6/8	6/7	1	6/5	6/4	6/2	6
Land use / Land-cover	5/9	5/8	5/7	5/6	1	5/4	5/2	5
Drainage Density	4/9	4/8	4/7	4/6	4/5	1	4/2	4
Elevation	2/9	2/8	2/7	2/6	2/5	2/4	1	2
Aspect	1/9	1/8	1/7	1/6	1/5	1/4	1/2	1

The AHP eigenvector technique was used to normalize the final weights to 1. This is accomplished by adding values in each column, after which each factor is divided by the sum of its respective columns. Hence, the normalized pairwise matrix (Table 3) is generated.

Inconsistency may occur because pairwise comparisons are conducted through subjective or personal judgments (Arunbose *et al.* 2021). Therefore, the Consistency Index (CI) and consistency ratio (CR) were determined to quantify the consistency of the comparison matrix. The first step to calculate the degree of CR involves a calculation of the principal Eigenvalue (λmax) using the Eigenvector technique (Table 3), and the consistency index (CI) was computed using (Saaty, 1980):

Table 3: Normalized pair-wise matrix and normalized weight of each thematic layer

Factors	Geomorphology	Lineament Density	Geology	Slope	LULC	Drainage Density	Elevation	Aspect	Normalized Weight	Eigenvector
Geomorphology	0.18	0.26	0.3	0.29	0.32	0.34	0.34	0.37	0.3	8.57
Lineament Density	0.14	0.21	0.27	0.26	0.29	0.3	0.3	0.34	0.26	8.5
Geology	0.13	0.18	0.24	0.22	0.25	0.27	0.27	0.31	0.23	8.52
Slope	0.11	0.16	0.21	0.19	0.21	0.23	0.23	0.26	0.2	8.6
Land use / Land cover	0.09	0.13	0.17	0.16	0.18	0.19	0.19	0.21	0.17	8.65
Drainage Density	0.07	0.1	0.14	0.13	0.14	0.15	0.15	0.16	0.14	8.79
Elevation	0.04	0.06	0.1	0.09	0.1	0.11	0.11	0.12	0.09	8.78
Aspect	0.02	0.03	0.05	0.04	0.05	0.06	0.06	0.07	0.05	10

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

n the number of factors; λ_{max} principal Eigenvalue

$$\lambda_{max} = \frac{8.57 + 8.50 + 8.52 + 8.60 + 8.65 + 8.79 + 8.78 + 10.00}{8} = 8.67$$

$$\therefore \ CI = \frac{8.67 - 8}{8 - 1} = 0.10$$

The next step determines CR as the confidence interval ratio to the random consistency index (RCI) (Table 4). This step ensures that the consistency analysis is accurate and validates the scale. CR was computed using (Saaty, 1980):

$$CR = \frac{CI}{RCI}$$

$$\therefore\ CR = \frac{0.10}{1.41} = 0.07$$

Since 0.07 is less than 0.1, it denotes a high consistency value for the assigned weights.

The Random Consistency Index (RCI) is calculated using Saaty's standard ratio index (Table 4). According to Saaty (1980), a CR value of less than or equal to 0.10 is acceptable for the analysis, while the weights must be re-evaluated if the consistency value exceeds 0.10, and any necessary changes should be made before analyzing (Prasad *et al.* 2008). Furthermore, the CR value of 0 (zero) suggests that the pairwise comparison has a high degree of reliability (Arunbose *et al.* 2021).

Table 4: Random Consistency Index (RI) values for n variables.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

Finally, the groundwater potential zone map was created using ArcGIS 10.5 with a weighted overlay analysis tool (Ghosh *et al.* 2020; Aykut 2021).

$$GWPZ = GMwGMr + GwGr + LDwLDr + SLwSLr + LULCwLULCr + DDwDDr + ELwELr + SAwSAr$$

Where GM is geomorphology, G is geology, LD is lineament density, SL is a slope, LULC denotes land use and land cover, DD denotes drainage density, EL is elevation, and SA is the slope aspect. The suffix w represents weight, while r indicates the rank of each layer, respectively.

RESULTS AND DISCUSSION

Table 5: Assigned rank and normalized weights of different sub-class of each thematic layer for groundwater potential zoning

Factors	Weight (%)	Sub-class	Rank	Overall weight
Geology	23	Granite	1	0.07
		Syenite	3	0.22
		Migmatite	2	0.14
		Pegmatite	4	0.30
		Quartz vein	4	0.28
Lineament Density (km/km^2)	26	0 - 100	1	0.06
		101 - 250	2	0.13
		251 - 450	3	0.2
		451 - 600	4	0.27
		>601	5	0.34

Slope (degree)	20	0.1 - 5.6	5	0.33
		5.7 - 11.3	4	0.27
		11.4 - 16.9	3	0.21
		17 - 22.5	2	0.13
		>22.5	1	0.06
Drainage Density (km/km^2)	14	0 - 93.7	5	0.33
		93.8 - 281.2	4	0.27
		281.3 - 468.6	3	0.2
		468.7 - 656	2	0.12
		>657	1	0.07
Land use/ Land cover (LULC)	17	Developed	1	0.07
		Barren	1	0.07
		Forest	4	0.28
		Cultivated land	3	0.22
		Wetlands	5	0.36
Geomorphology	30	Flat	5	0.23
		Peak	1	0.05
		Slope	2	0.09
		Ridge	1	0.04
		Valley	5	0.22
		Shoulder	1	0.05
		Foot slope	3	0.14
		Pit	4	0.18
Elevation (masl)	9	289 - 300	4	0.40
		300 - 350	3	0.30
		350 - 400	2	0.20
		>400	1	0.10
Aspect (degree)	5	-1	5	0.34
		0 - 112.5	4	0.29
		112.5 - 247.5	3	0.21
		247.5 - 360	2	0.14

Geomorphology

Groundwater occurrence, prospection, and movement are all governed by geomorphology. It represents the subsurface formation that controls the groundwater movement (Saravanan *et al.* 2020). Geomorphological units can be classified according to their landforms, including plains, terraces, volcanoes, hills, valleys, and mountains, valleys, flat plains, ridges, slopes, hallows, pits, shoulders, and peaks are the common geomorphological types that make up the study area (Figure 3).

Geology

Geology completely determines the penetration and percolation of groundwater. As a result, it is a crucial criterion for assessing groundwater potential (Aju *et al.* 2021). Geology is vital in determining groundwater's source, and distribution regulating water's surface runoff and percolation. Crystalline rocks of the Precambrian age underlie the entirety of the study area. Hydrogeologically, these rocks are categorized as hard rocks with low primary porosity and permeability.

However, secondary porosity and permeability structures such as extensively deep weathering, fracturing, and jointing on rocks serve as an interconnecting means and room for groundwater movement and accumulation (Pawar *et al.* 2008).

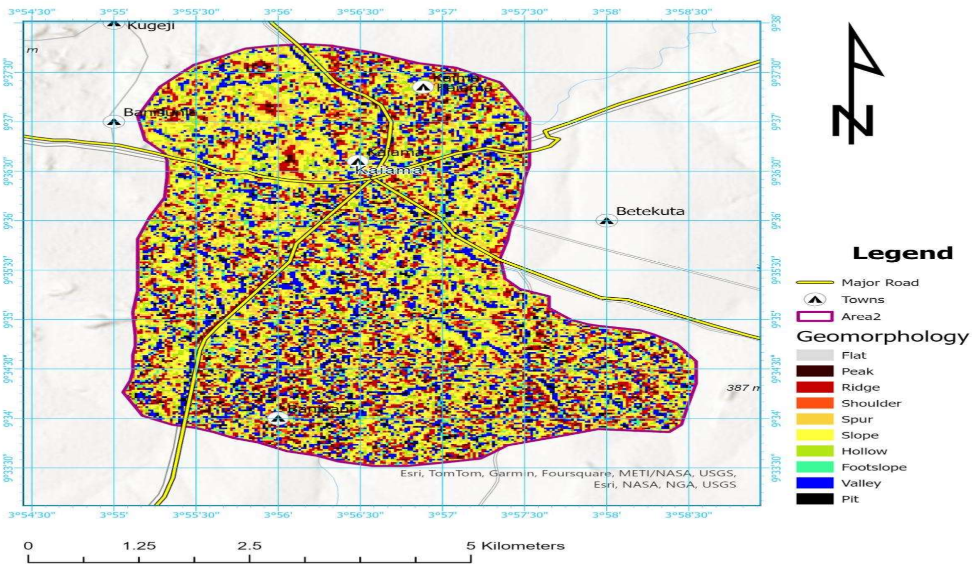

Figure 3: Geomorphology map of the study area

The lithologies found in Kaiama, north central Nigeria are displayed in (Figure 4). About 57% of "granite" occupies a large portion of the study area, followed by "syenite", which occupies 18% of the study area. The other major geological units present in the region are migmatite (11%), pegmatite (8 %) and quartz-vein (6%).

The study area is predominantly composed of granite, followed closely by syenite. These are crystalline rocks with a compact structure with little to no porosity. However, this type of hard rock holds moderate to high groundwater depending on the intensity of secondary porosity such as fracture, lineament, fault, etc. (Seenipandi *et al.* 2019). For groundwater recharge, the more weathered rocks, less dense, and more prone to fracturing make better infiltration and runoff conditions (Krishnamurthy *et al.* 2000). Each rock type was given a specific weight based on these factors (Table 5.0).

Lineament density (Ld)

Lineaments are the linear features of tectonic origin identified as long, narrow, and relatively straight alignments visible in satellite images. A lineament may represent a fault, fracture, and master joint; a long and linear geological formation; a straight course of streams; vegetation alignment or topographic linearity (Pradhan, 2009). They are features with secondary permeability and give a clue to the movement and storage of groundwater. Therefore, they are important guides for groundwater exploration (Sener *et al.* 2005). Recently, many groundwater exploration projects conducted in various countries have obtained higher success rates when sites for drilling were guided by lineament mapping (Teeuw 1995).

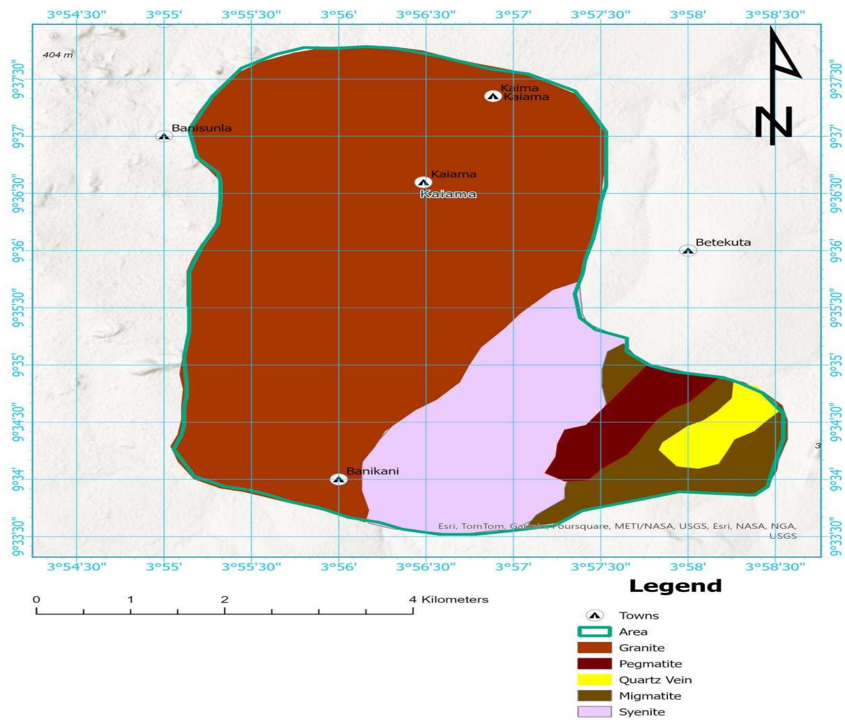

Figure 4: Geology map of the study area

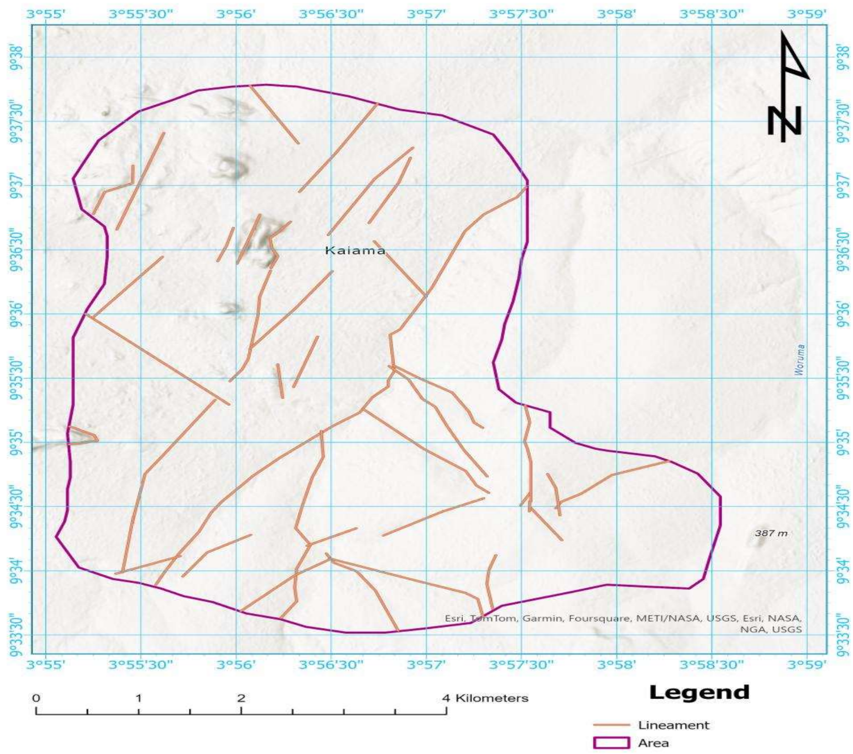

Figure 5: Lineament map of the study area

To convert the lineament pattern into measurable quantity, the lineaments have been identified with the aid of lineament filters and visual comments on Landsat 8 (Figure 5). For this purpose, the lineament density (Ld) was calculated based on the grid cells method (Rahmati *et al.* 2016). Groundwater potential increases with increasing lineament density values (Varade *et al.* 2018). The obtained lineament density was classified as follows: [0-100] very low (64%), [101-250] low (11%), [251-450] moderate (17%), [451-600] high (5%) and [601-890] very high (3%). The study area is controlled by very low lineament density, with the least aerial extent of very high lineament density in the southwestern part (Figure 6). It is also observed that high lineaments are located in pegmatite and syenite-dominated regions, which could be due to deep faults or fractures in the area.

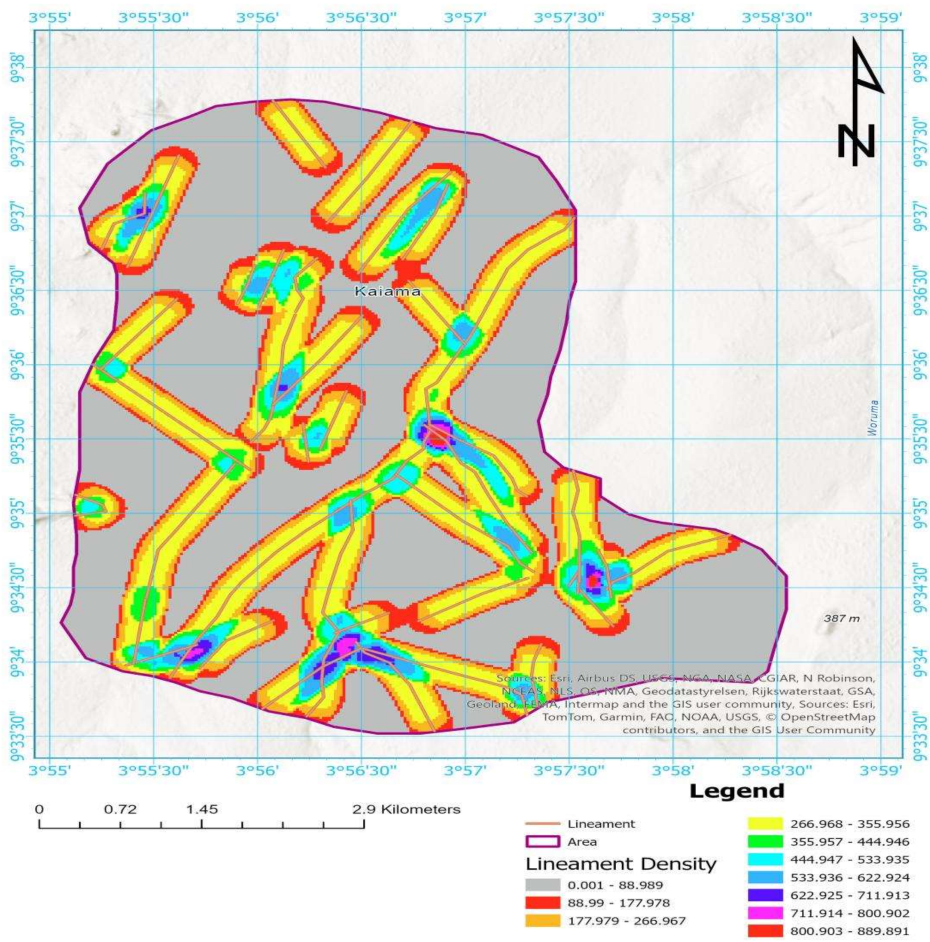

Figure 6: Lineament Density (Ld) map of the study area

Slope

Because the slope has a direct influence on the surface runoff mechanism, it is critical for groundwater recharge (Zghibi *et al.* 2020). Preliminary investigations have revealed that the low-slope regions have a good potential for groundwater storage due to the extended residence time for rainwater infiltrating the subsurface. However, steep slope regions, on the other hand, possess poor groundwater potential due to rapid water runoff from the landscape (Igwe *et al.* 2020).

The slope of Kaiama district was split into five classes: 0.1-5.6° (very good potential), 5.7-11.3° (good potential), 11.4-16.9° (moderate potential), 17-22.5° (poor potential), and 22.6-26.2º (very poor potential) (Figure 7). The first class with very good potential occupies 72 % of the study area due to the very flat slope indicating that the area has a slope conducive to water retention, ideal for a good recharge, and aids low runoff.

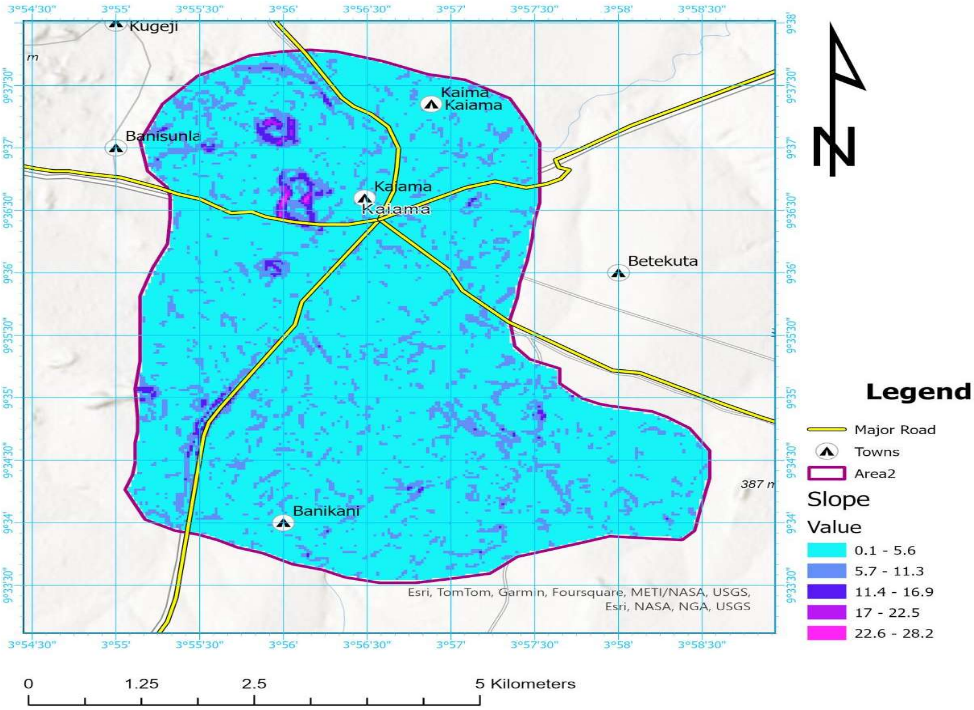

Figure 7: Slope map of the study area

Land use/land cover (LULC)

Land use/land cover pattern is among the most important elements regulating surface runoff due to evapotranspiration, penetration, and condensation all dependent on factors like vegetation type and soil wetness. Groundwater depletion occurs in wastelands and densely populated areas, while the water table rises in forest areas due to low runoff and high subsurface infiltration (Sahoo *et al.* 2017).

The land use of the study area is classified into five classes: developed, forest, barren, planted/cultivated, and wetlands (Figure 8). Approximately 57% of the total area is covered by planted/cultivated land for agricultural purposes, and 22% of the area is filled with developed settlements. Wetlands such as flood plains represent 16%, 4% of the area is covered by barren lands and exposures while the remaining 1% represents forest. Classification of land use for weighted analysis was decided based on the land-use type, area coverage properties to infiltrate water, and their characteristics to hold water on the ground surface (Table 5.0).

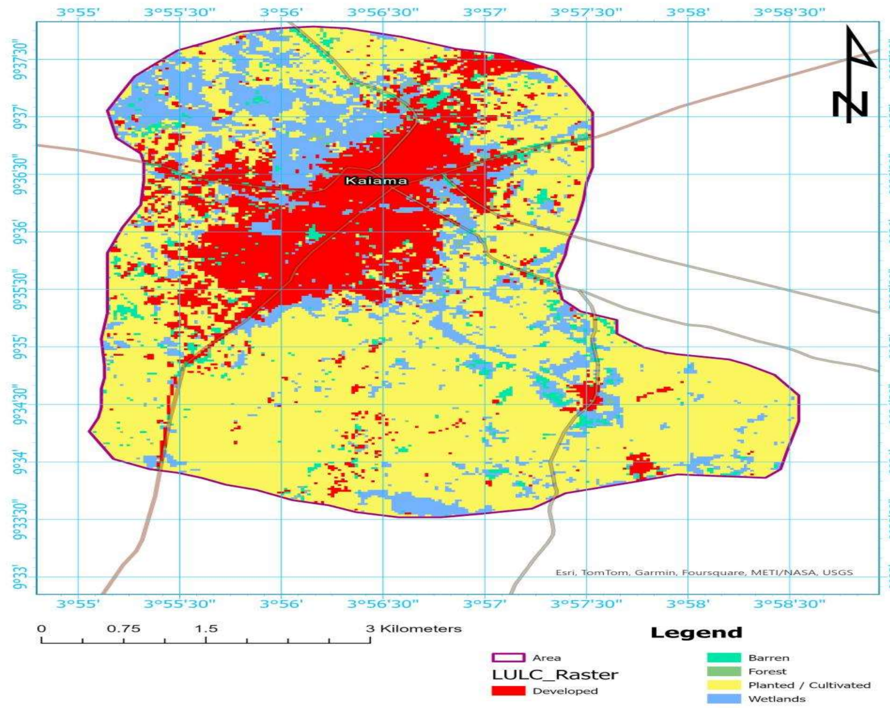

Figure 8: Land Use/Land Cover map of the study area

Elevation

Approximately 70% of the study area is mountainous. The elevation map was generated from ASTER DEM data using the GIS ArcMap 10.1 and constructed as an elevation in raster format. The elevation map of the area was classified based on the shape and features of the terrain into four different sub-classes: 289-300 masl considered as 'very good'; 300-350 masl considered as 'good'; 350-400 masl considered as 'poor'; and 400-419 masl considered as 'very poor'. As described above, an elevation of 289–419 masl was grouped into four different elevations above mean sea level as hilly and steep slopes, and it has less influence on groundwater occurrence. The pairwise comparison shows that areas with a rolling hill shape and flat terrain are calculated as a higher weight and a hilly and mountainous shape was calculated as a lower weight, and the reclassified elevation map was produced based on these principles (Figure 9).

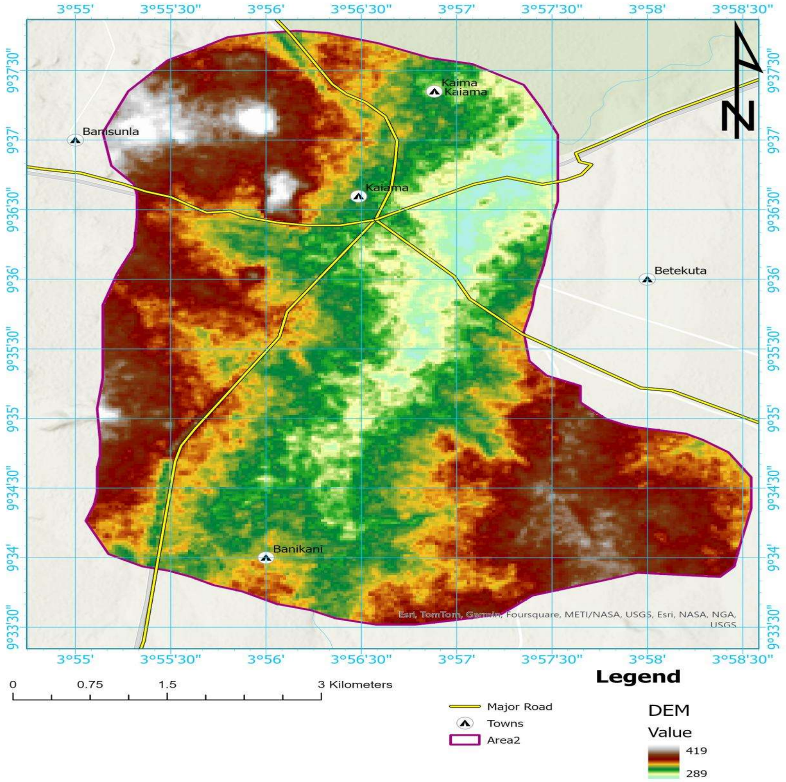

Figure 9: Elevation map of the study area

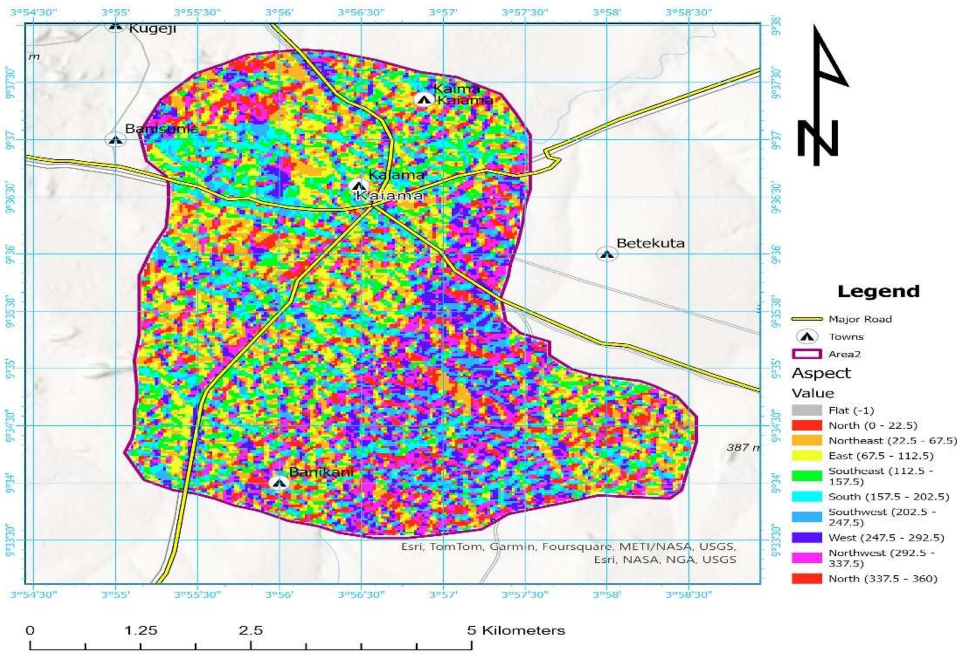

Figure 10: Slope Aspect map of the study area

Aspect

An aspect map plays a vital role in understanding groundwater potential by showing the direction slopes face, which influences temperature and sunlight exposure. Derived from a Digital Elevation Model (DEM), this map categorizes slopes into different directions, affecting groundwater retention. Slopes facing north, northeast, and east (0 - 112.5 degrees) and flat surfaces (-1) receive less sunlight, keeping them cooler with lower evaporation rates, which helps preserve groundwater. In contrast, slopes facing south, southeast, southwest, and west (112.5 - 360 degrees) get more sunlight, especially during the hottest parts of the day. This leads to higher temperatures and more evaporation and evapotranspiration, causing greater groundwater loss (Figure 10).

Groundwater potential zones and map

After computing the final normal weights of all the thematic layers and their features, they were converted into a raster format. The groundwater potential map values were classified into five groundwater potential zones: very high potential, high potential, average potential, poor potential, and very poor potential zone (Figure 11).

The study revealed that 45% (51.93 Sqkm) of the study area exhibits very low groundwater potential, whereas the low potential zones represent about 21% of the total area of the study (24.23 Sqkm). Around 13% of the total area (15 Sqkm) is rated as having average potential zones, while 6% (6.94 Sqkm) is classified as having high potential zones and finally 15% (17.3 Sqkm) of the study area is classified as very high potential zones (Table 6).

Table 6: Classification of groundwater potential zones and their respective area

Potential zones	Area covered (Sqkm)	Area covered (%)
Very Low	51.93	45
Low	24.234	21
Average	15.002	13
High	6.924	6
Very High	17.31	15

The low and very low regions of the groundwater potential map fall mostly on the igneous rock at the center of the study area, due to the crystallized structure of granite and little to no fracture present in the study area reducing the amount of groundwater recharge of the zones, the average zone is located at the northwest of the map which is common with gentle slopes and presence of fractures which aids in recharge of groundwater. The high and very high potential zones are much more than the average zone due to valleys, pits, faults, pegmatitic intrusions, and fractures which aid the storage and pathway of groundwater.

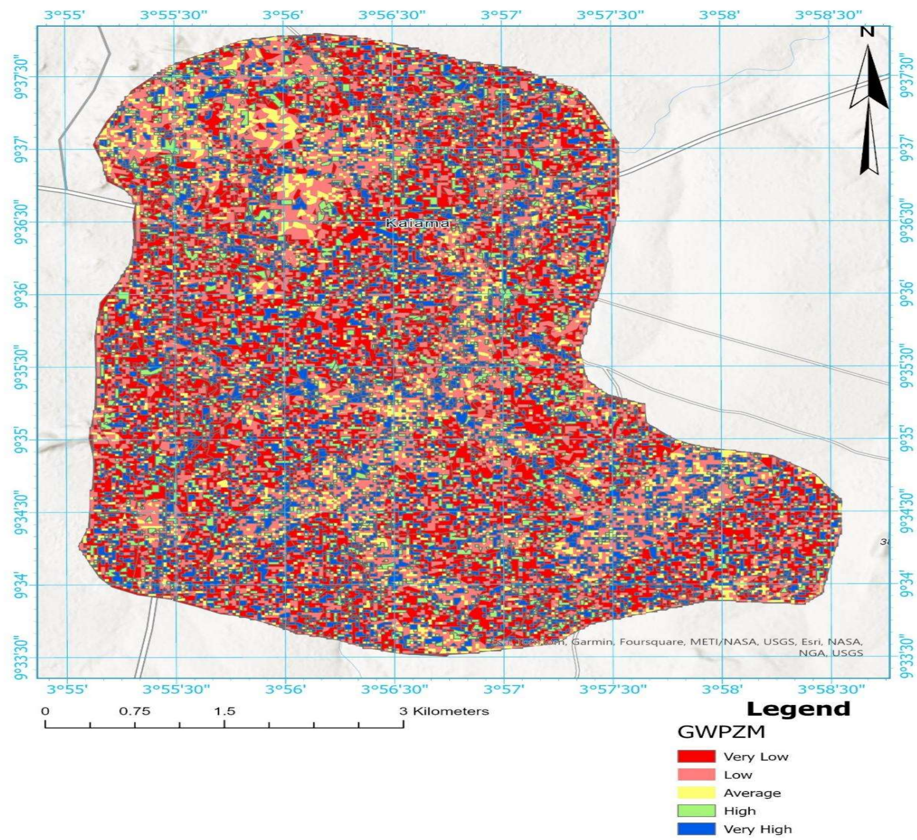

Figure 11: Groundwater potential zones of the study area

Validation of Groundwater potential zone

The validation of the groundwater potential map adopted the VES method, which measures subsurface resistivity and is a reliable indicator of groundwater potential. For this validation, we used VES data points from 20 locations.

To quantitatively assess the predictive accuracy of the groundwater potential map, we applied the Receiver Operating Characteristic (ROC) analysis. This involved calculating the True Positive Rate (TPR) and False Positive Rate (FPR) at various threshold settings. The ROC curve was plotted with FPR on the x-axis and, TPR on the y-axis, resulting in an Area Under the Curve (AUC) value of 0.60 (Figure 12). This AUC value suggests a moderate level of agreement between the predicted groundwater potential zones and the actual VES measurements, indicating the model has good predictive value, however, there is room for improvement, particularly in hard rock terrains where the presence of high-structural features such as faults and fractures can affect groundwater distribution.

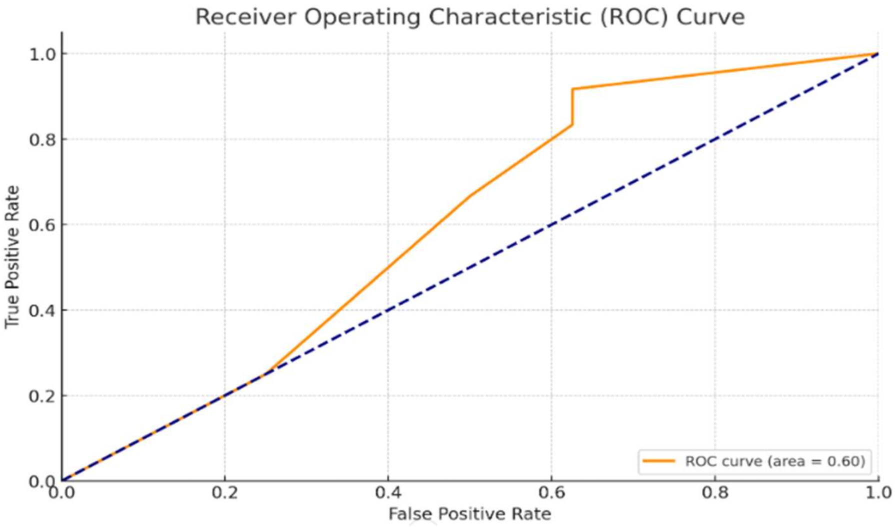

Figure 12: ROC curve of the GWPA map in Kaiama

CONCLUSION

As populations grow, identifying areas with high, medium, and low groundwater potential is vital for making informed policies and managing resources effectively. This research has created a specialized mapping tool using various geological and hydrological parameters to help decision-makers. The groundwater potential in the Kiama district was evaluated using a specialized analyzer method in conjunction with the MCDM technique. The normalized weight and rank of each element and its sub-classes affecting groundwater potential probability in the region were successfully determined using the MCDM-AHP approach. The resulting Groundwater Potential (GWP) map was subsequently created, providing a comprehensive understanding of the area's groundwater resources. The result showed that 15 %, 6 %, 13 %, 21 %, and 44 % of the study area fall under a very high, high, average, low, and very low groundwater potential zone, respectively. Validation against 20 Vertical Electrical Sounding (VES) points at a depth of 100 meters yielded an Area Under the Curve (AUC) of 60%, demonstrating good predictive accuracy. Therefore, the data validation process confirms the correctness of the AHP forecast information. In addition, the utilization of multiple techniques proved to be an effective and efficient tool in subsurface groundwater delineation and exploration. Lastly, in areas with high water demand, it is essential to prioritize planning and allocation of resources in building wells and boreholes focusing on the areas with very high and high groundwater potential zones to optimize water supply. However, areas classified as low potential zones may not be suitable for extensive groundwater extraction, and alternative sources should be explored.

DECLARATION

Conflict of Interest: The authors hereby declare that there are no conflicts of interest associated with this research work. We affirm that no personal, financial, or professional interests have influenced the design, execution, or presentation of the research in any way. The findings and conclusions presented in this manuscript are based solely on objective and unbiased scientific inquiry.

Conflict of Interest: On behalf of all authors, the corresponding author states that there is no conflict of interest.

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