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AN INTEGRATED REMOTE SENSING, GEOGRAPHIC INFORMATION SYSTEM AND ANALYTICAL HIERARCHY PROCESS FOR DETERMINATION OF GROUNDWATER POTENTIAL IN KEFFI-GRA AND ENVIRONS

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ABSTRACT

Water, a universal solvent, is indispensable to all and has no adversary. The study area has experienced minimal depletion of some groundwater points, specifically boreholes. The groundwater potential of Keffi-GRA and its environs was assessed using remote sensing (RS), geographic information systems (GIS), and analytical hierarchy process (AHP) methods/techniques. These methods were adopted due to their ability to offer improved accuracy, visualization, reduced time and costs, and enhanced decision-making. The remotely sensed data used were Landsat 8 OLI (30 meters resolution) and SRTM DEM (30 meters resolution), while the GIS analysis was carried out on Arcgis Pro. The GIS analysis helped in delineating six thematic Map layers that influence the occurrence of groundwater (land use/land cover, slope, drainage density, water table, elevation, and rainfall); they were generated and weighted based on their importance using AHP. All the influencing factors were integrated and computed using the weighted overlay analysis tool on the software to generate the groundwater potential zones, five (5) zones where delineated, which reveals the area coverage of groundwater potential as 466m^2/0.47km^2 (very low) covering 2.6% portion, 5,384m^2/5.38km^2 (low) covering 29.23% portion, 3,416m^2/3.42km^2 (moderate) covering 18.85% portion, 7,357m^2/7.36km^2 (high) covering 40.68% portion, and 1,514m^2/1.51km^2 (very high) covering 8.3% portion. To validate the results, a total of 90 groundwater points of boreholes and 20 hand-dug wells were used as validation points. Hence, the results from remote sensing, geographic information systems, and the analytical hierarchy process indicate the study area to have a moderate to high groundwater potential, with minor variations in some parts of the study area, therefore can be utilize for a moderately efficient groundwater management.

Keywords: Groundwater, Boreholes, Geographic Information System, Remote Sensing, Analytical Hierarchy Process

INTRODUCTION

Groundwater is one of the known and feasible substitutes or alternatives of getting portable water in Nigeria, as the cost of exploitation via boreholes and other groundwater extraction sources is a bit flexible as opposed to traditional surface water programs, which require significant construction of reservoirs, dams, and pipe network connections, among other things (Adeyeye et al., 2019).

Approximately 95% of the freshwater on Earth comes from groundwater resources (Das et al., 2018). It occurs below the water table, occupying the spaces between grains in bodies of sediments and clastic sedimentary rocks, basement rocks, cracks, and crevices of rock (Diary and Lanja, 2016). Borehole construction in Nigeria became prominent in the 1980s through the government and intervention by international donor agencies like UNICEF, UNDP, and the EU, among others (Okhuebor, 2020). Since then, more groundwater points, or boreholes, have been drilled; according to (Oni et al., 2020), more than 60% of Nigerians rely on these sources for their water supply. It's a general belief among people that the increase in the numbers of boreholes is because of the failure of the government to provide its people with sufficient and portable water supply for their consumption. This situation had caused a significant increase in indiscriminate exploitation of groundwater resources and incessant sitting of boreholes which could leads to failure in some of the borehole's overtime, as witnessed in some borehole points. Therefore, it is important to have a thorough awareness of the research area groundwater potentiality and situation.

According to (Rao et al., 2021), he opines that based on his studies, hard rock terrain is complex in exploring groundwater because of its nature of occurrence, storage, and the distribution due to some geological factors. Similar studies emphasize that the most prolific water source in basement terrains is the aquifers (a geologic formation significantly saturated, porous and permeable materials which hold a significant amount of groundwater recharge wells and springs) (Okpoli & Ozomoge, 2020).

The study area comprises of regions of dense population and in some areas arable vegetated and non-vegetated land, with a possible estimation of 90% of the houses around are relying on boreholes and hand-dug wells (groundwater points) as the only source of potable freshwater, as it is peculiar in most developing areas (Obaje et al., 2023).

Remote Sensing (RS) and Geographic Information System (GIS) have a great potential in trying to examine and study groundwater flow and potential (Hougbagnon et al., 2021). In view of this assessment, the goal of this study is to highlight some of the possible means of applying RS and GIS in groundwater studies, as used in this research for analysis and result presentation (GIS-based models), being one of the recently widest accepted technique in groundwater evaluation and studies (Zhu & Abdelkareem, 2021).

Description of the Study Area

The study area, situated in Keffi-GRA, falls within Keffi Sheet 208NE, within the surrounding area of the Keffi Local Government Area in Nasarawa State. It is situated between latitudes 7° 53′ 39.82″E and 7° 55′ 12.49″E and longitudes 8° 51′ 17.06″N and 8° 52′ 57.08″N. These locations rank among the most populated areas within the town. The study area is accessed by the major highway of the Keffi-Akwanga expressway and minor roads and footpaths.

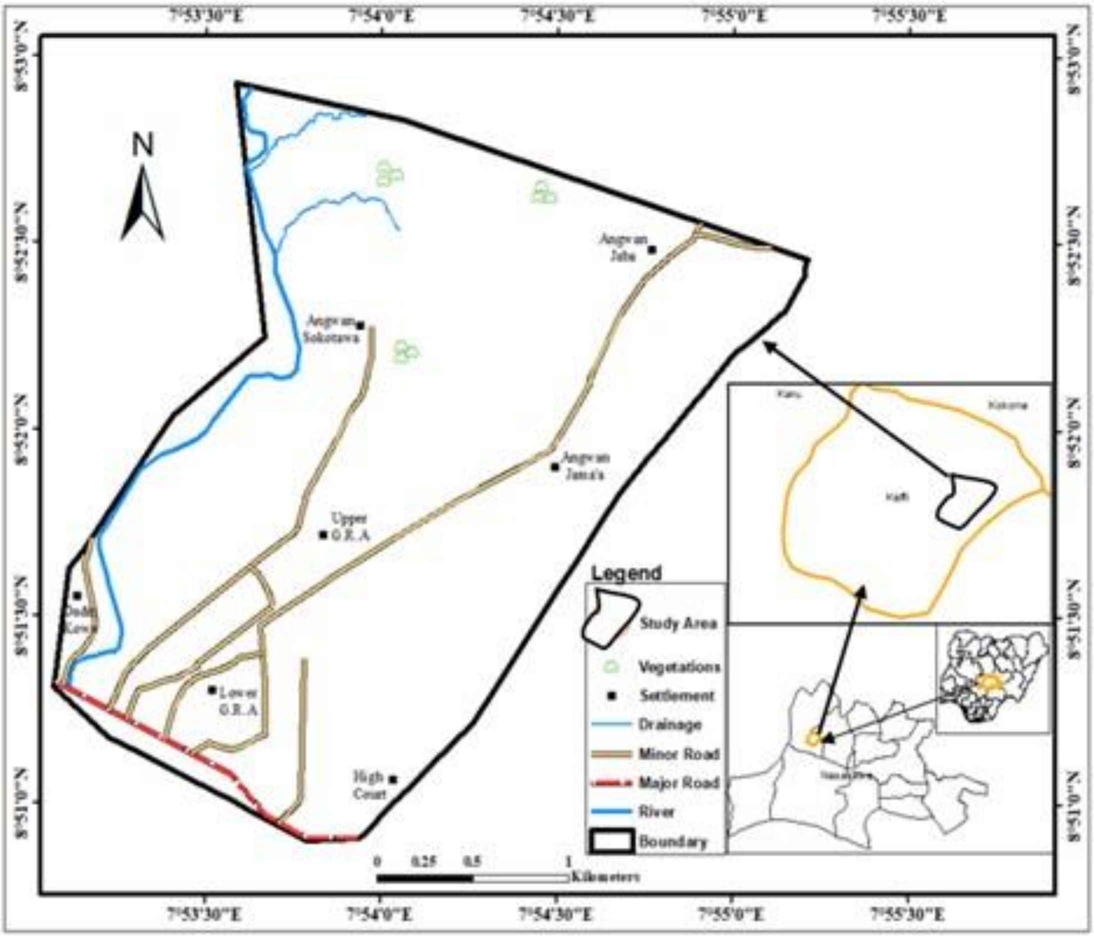

Figure 1: Map of Keffi-GRA and Environs

Geology and Hydrogeology of the Study Area

The underlying geology of Keffi-GRA and environs reveals that the major rock type distributions are predominantly composed of gneiss, with a little gradation into granitic gneiss trending towards the northern part of the study area (Figure 2).

In essence, this area is drained by the River Antau and a number of subsidiary tributaries that flow in a dendritic pattern southward. In most cases, their flow directions align with the joints of the crystalline basement rocks beneath them (Anudu et al., 2012).

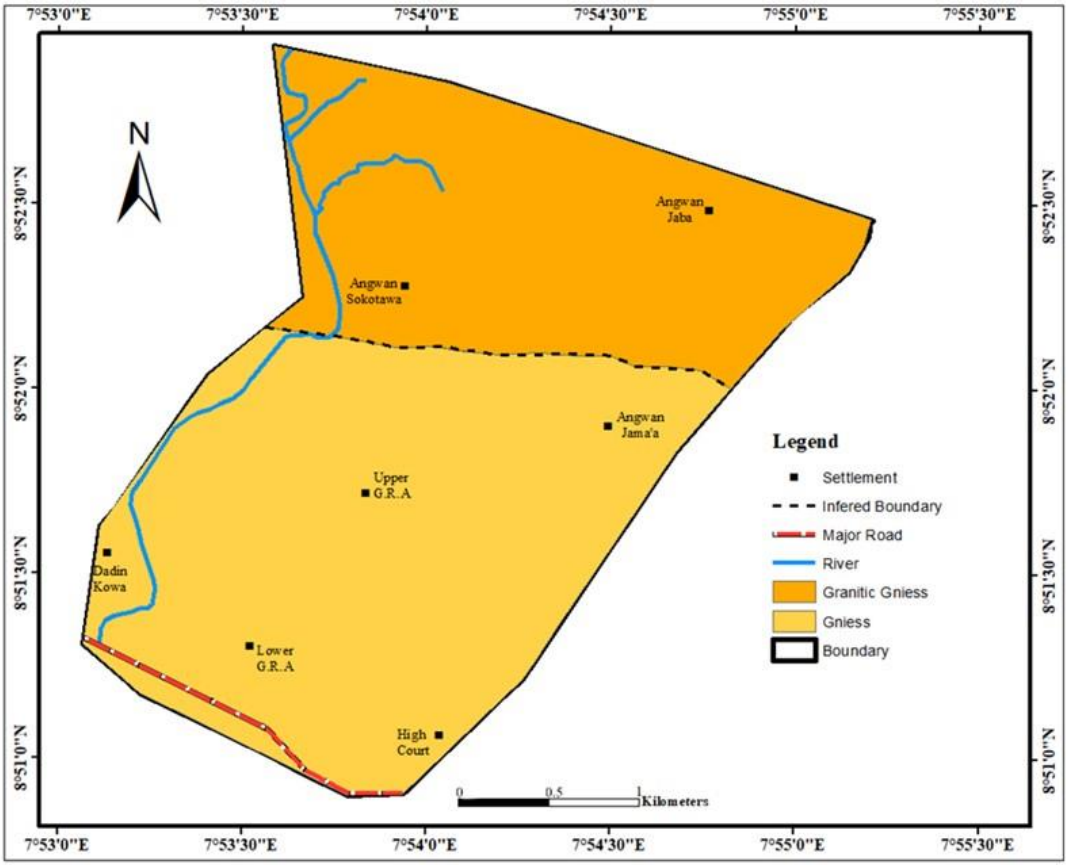

Figure 2: Geology of the Study Area
Source: Department of Geology, NSUK (2023)

MATERIALS AND METHODS

Basically, numerous types of data sets were adopted for the present work, which include both the primary and secondary data sets. Detailed sources of the database are given in Table 1. Arcgis Pro was used for most of the GIS analysis, while quantitative computation was carried out on Microsoft Excel. Remote Sensing (RS)-Geographic Information System (GIS), and the Analytical Hierarchical Process (AHP) technique where utilize in the process of the groundwater potential zones delineation, where six thematic map layers where delineated, which include: landuse/landcover, slope, drainage density, water table, rainfall, and Topographic Elevation.

Class weights and scores was assigned to each thematic data set based on Saaty' and Vargas (1991) Analytic Hierarchy Process (AHP), this was adopted to characterize each thematic map into very high, high, moderate, low, and very low. Each class relative importance within the same map was also compared to each other pairwise, and six essential matrices was prepared for assigning weight to each class. A combination of thematic maps using the weighted overlay spatial analysis tool in Arcgis Pro was used to determine groundwater potential zones spatial distribution following the equation below.

GPZ=$\sum_{i-1}^{n} wi\ x\ ri$ (1)

Where n indicates the number of criterion, wi indicatetes the number of relative weight of criterion r and ri which represents the standardized scores

Multi-criteria evaluation based on AHP was used to compute ranks and weights, which was then reclassified into six groundwater potential zones (very high, high, moderate, low, and very low).

Groundwater Potential Zones = RF+LD+DD+SL+LU/LC+TP (2)

Where:

RF = Rainfall
WT = Water Table
DD = Drainage Density
SL = Slope
LU/LC = Landuse/Landcover
TP = Topographic Elevation

The influencing factors have been used for the delineation of groundwater potential zones. The analytical hierarchy process (AHP) is one of the most popular multi-criteria decision-making techniques (Aliabad et al., 2018); as such, it has been used for this analysis. In order to help arrange the criteria in a hierarchical order using the pair-wise comparison matrix, AHP has been utilized to identify the individual thematic map layers along with their rank and priority. In accordance with Saaty's (1980) assessment, the consistency ratio, eigenvalue, and vector matrix have also been computed. AHP is a straightforward, easy, reliable, and efficient technique that may be used to define groundwater potential zones (Igwe et al., 2020; Aju et al., 2021). Data may be transformed into information that managers and policymakers can use due to the integration of GIS and AHP (Guru et al., 2017). As a result, the themes and their attributes were given weights on a range of 1 to 6 according to their impacts. To define the groundwater potential zones, the weighted overlay analysis in Arc GIS software incorporated all the themes and their classes with normalized weights. The purpose of this research is to use remote-sensing, GIS and AHP to identify the Ground Water Potential Zones of Keffi-GRA and environs,

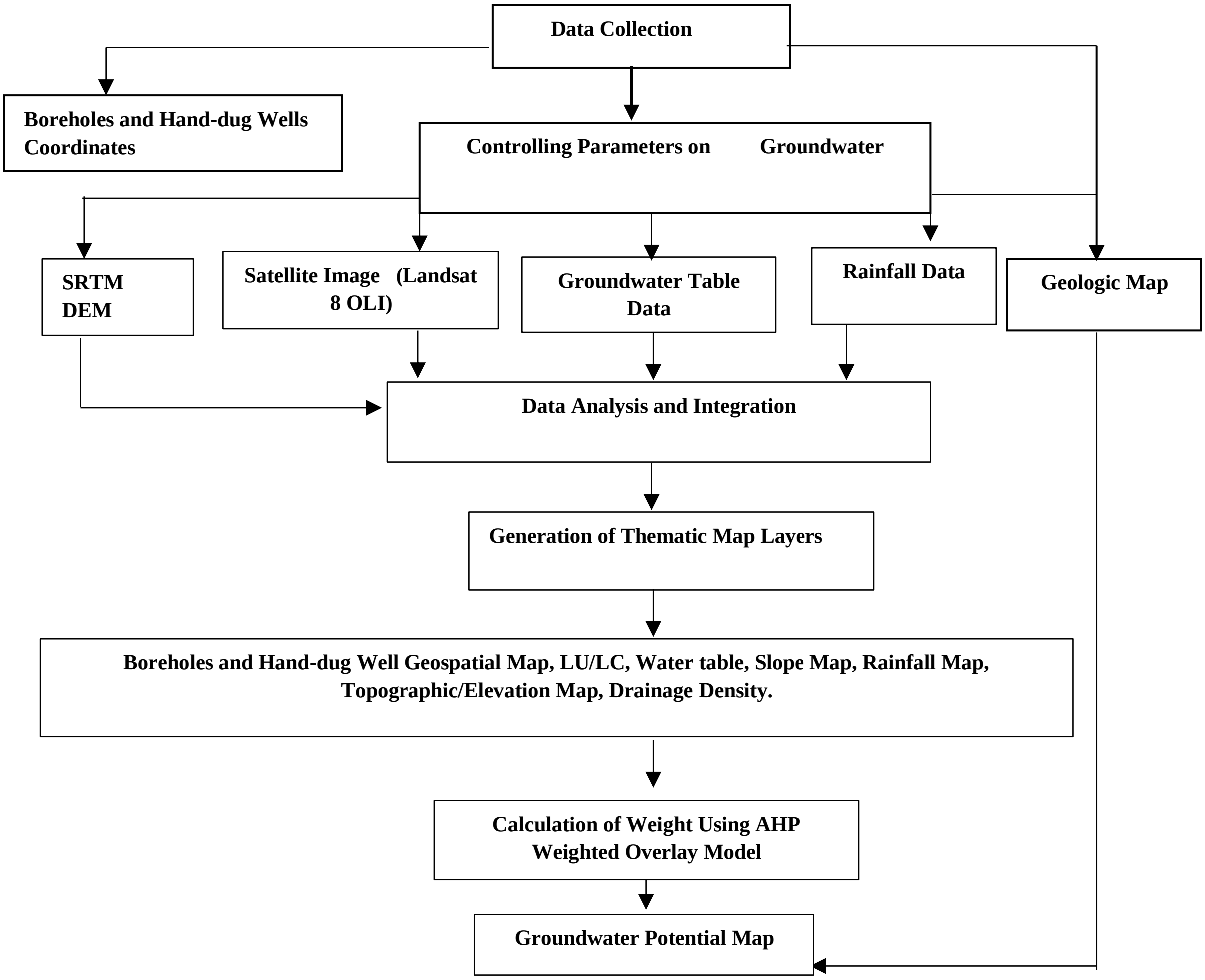

Figure 3: Flowchart of the different methods adopted for this study

Table 1: Summary of Dataset

Dataset	Resolution/Scale	Format	Source
Landsat 8OLI	30m	Digital	https://www.earthexplore.com
SRTM-DEM	30m	Digital	https://www.earthexplorer.com
Geologic Map	1:12,500	Digital	Department of Geology, NSUK/ Field Observation
Rainfall Data	0.4° x 0.4°	Digital	https: Chrsdata.eng.uci.edu/
Water Table Data	-	Analogue	Hand dug wells within the study area
Geo-location of Groundwater Points	-	Digital	Garmin handheld GPS

Analytical Hierarchy Process (AHP) of Groundwater Potential Criterion Evaluation

The Analytical Hierarchy Process (AHP) approach developed by Saaty (1980, 1986, and 1992) was adopted in this study as a decision – assistance technique or method to present a final weight assigned to individual generated thematic map layers and their respective features that aid in groundwater potential evaluation.

The study was carried using the groundwater criterion (land use/ land cover, slope, water table, drainage density, rainfall, and elevation) and sub-dividing them into their unit, class, potential ranges, potential ratings as well as weight in accordance with the role it played on the groundwater potential of the study area, the result was further normalized by Saaty's AHP and the eigenvector method was adopted to reduce the possible errors associated with the assigned weight.

The attribute of each of the thematic map layer were assigned weightage 1- 5, depending on the relative contribution to the groundwater potential, this in line with related approach by Mukherjee et al., 2012, Hougbagnon et al., 2021, among others.

Presented in Table 2 is the result of Groundwater Potential in the Study Area

Table 2: Saaty's Pairwise Comparison Scale

Intensity of Importance	Definition	Explanation
1	*Equal Importance*	Two factors contribution equally
2	*Weak or slight*	
3	*Moderate importance*	Experience and judgement slightly favour one factor over another.
4	*Moderate importance*	
5	*Strong Importance*	Experience and judgement strongly favour one factor over another.
6	*Strong Plus*	
7	*Very Strong*	One factor favoured very strongly over another, with dominance demonstrated in practice.
8	*Very, very strong*	One factor has total dominance over one another
9	*Extreme Importance*	

Note: If factor X is compared to factor Y. and factor X is assigned one of the numbers above (1-9), then factor Y will be assigned the reciprocal value of X (that is, 1 / value for X)

Table 3: Groundwater Potential Criterion Table

Groundwater Potential Criterion	Unit	Class	Potential Class Ranges	Potential Class Ratings	Weight (%)
Land-use/ Landcover (LULC)	Level	Built-up	Very low	1	**38.2**
		Settlement	Low	2	
		Bare land	Moderate	3	
		Sparse Vegetation	High	4	
		Dense vegetation	Very high	5	
Slope	Deg.	0.006 - 0.734	Very high	5	**4.1**
		0.735 - 1.33	High	4	
		1.34 - 1.97	Moderate	3	
		1.98 - 2.79	Low	2	
		2.8 - 5.63	Very low	1	
Water Table	Meter	1.31- 1.67	Very high	5	**10.7**
		1.68 - 2.02	High	4	
		2.03 - 2.37	Moderate	3	
		2.38 - 2.72	Low	2	
		2.73 - 3.07	Very low	1	
Drainage density	SqKm	19.4- 54.8	Very low	1	**6.9**
		54.9 – 90.1	Low	2	
		90.2 – 126	Moderate	3	
		127 – 161	High	4	
Rainfall	Mm	163-196	Very high	5	**33.3**
		130-145	Very low	1	
		145-150	Low	2	
		150-155	Moderate	3	
		155-160	High	4	
		160-180	Very high	5	
Elevation	M	280- 289	Very high	1	6.8
		290 – 296	High	2	
		297 – 305	Moderate	3	
		306 – 317	Low	4	
		318 – 327	Very low	5	

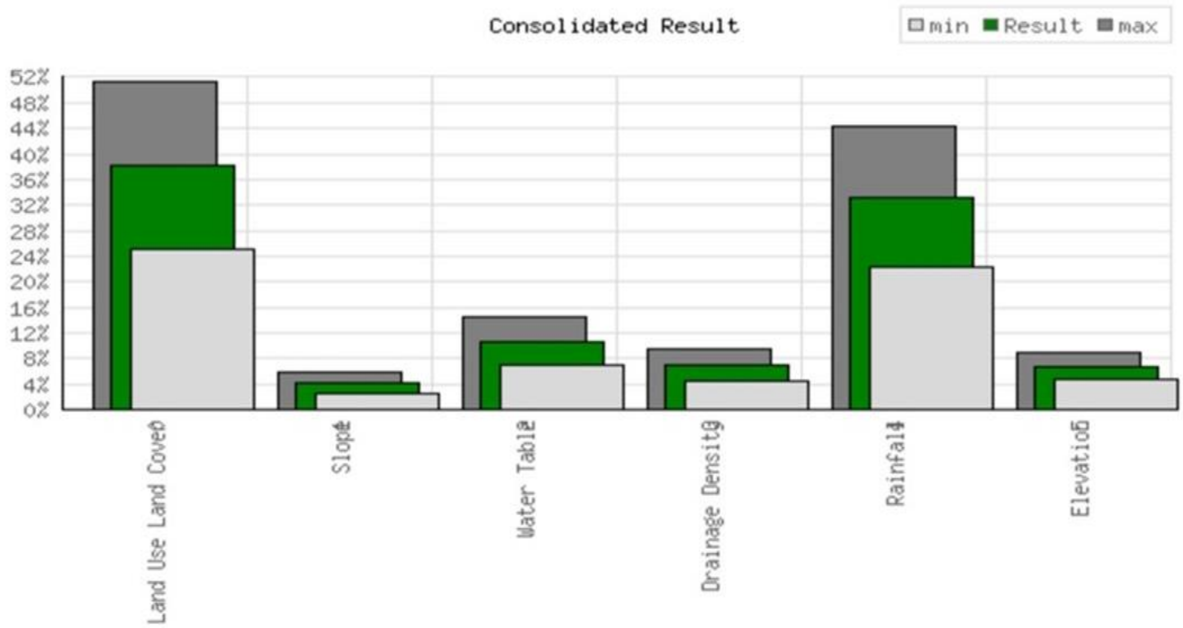

Figure 4: Bar chart of consolidated result of criterion

RESULTS AND DISCUSSION

The obtained results comprise all influencing factors that affect the occurrence of ground water the result is being presented as individual thematic map layers of the six (6) parameters that were integrated into the AHP system.

Generally, the area has one major rock lithology (Gneiss), though it differs in terms of texture towards the northern part of the study area, grading into granitic gneiss. The geology of the area wasn't integrated into the AHP system, but was used to determine the possible aquifer characteristics of the area, thus the type of recharge pattern and aquifer characteristics (porosity and permeability) and storage capacity of the surrounding rock (gneiss), which is majorly influenced by fracturing aquifers and usually exhibits low to moderate porosity (around 1-5%) with low to moderate permeability (around 10^-6 to 10^-6 m/s). This is a result of the gneiss's metamorphic origin and mineral composition (e.g., quartz, feldspar, mica), which reduces its permeability (Slater, 2007).

Land Use/Land Cover

Land use land cover is one of the major factors that determine the existence and development of groundwater. The land use/land cover of a certain area depends on geomorphology, agro-ecology, climate, as well as human activities (Bufebo & Elias, 2021). It is one of the major factors affecting groundwater occurrence and availability. The type and nature of LULC on groundwater controlling in the order of increment are put as: built-up (very low), settlement (low), bareland (moderate), sparce vegetation (high), and dense vegetation (very high). Sparce vegetated area and dense vegetation area tend to be the most favorable factors that give rise to groundwater potential in the study area (Figure 5). Built-up locations and settlement in the study area tends to have low and very low potential of groundwater, which could be tied up to the human anthropogenic activity that normally takes place within the human environment, LU/LC tends to be the most prevailing factor that influence the groundwater potential, which weighted 1st with a normalized weight of comparison as of 38.2 % (Table 3) to the groundwater potential.

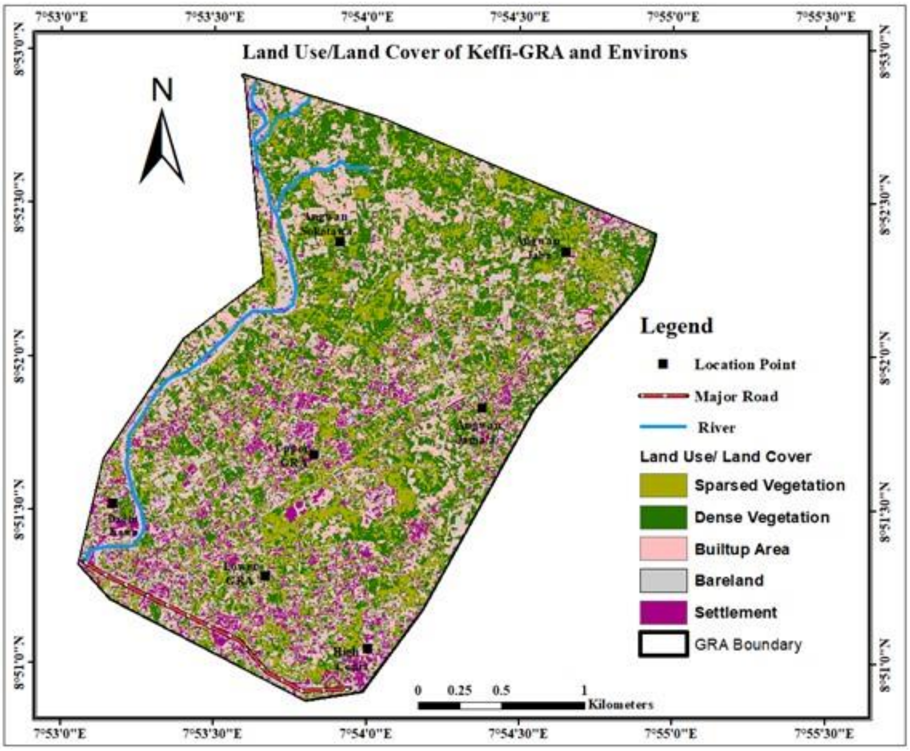

Figure 5: Land-use/Land Cover of the Study Area

Slope

Slope is one of the main factors influencing how surface water penetrates the subsurface. High slope locations tend to allow less infiltration, while gentle slope areas tend to offer more time for percolation due to slower surface run-off (Danjo & Ishizawa, 2020). According to Figure 6, the study area's general slope falls between 0.0059° and 0.734° (very high), 0.734° and 1.33° (high), 1.34° and 1.97° (moderate), 1.98° and 2.79° (low), and 2.8° and 5.63° (extremely low). While high-slope areas are the primary barrier to groundwater recharge, low-slope areas are conducive to groundwater recharge. Generally, the study area is a moderate to low laying terrain, therefore slope weighted 6th with a normalized weight of 4.1% being the least significant factor to groundwater potential (Table 3).

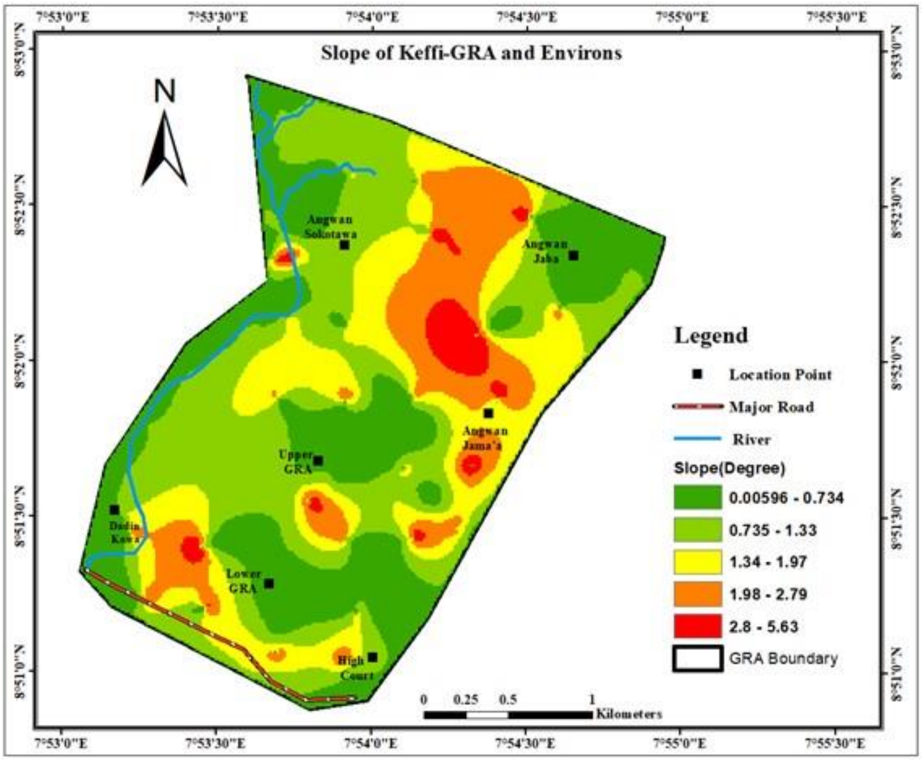

Figure 6: Slope of the study area

Water Table

The water table, which is inversely proportional to the groundwater potential of an area, serves as the boundary between the aeration zone and the saturation zone (Lionel et al., 2023). Thus, when rain seeps into the groundwater level, it percolates through the gaps or openings of soil and rock fractures, which will accumulate underground, and the surface is referred to as the water table. Groundwater level of Keffi GRA and environs reflect the hydraulic head points of the groundwater condition of the area. The groundwater level in the study area varies from 1.31 to 1.67 m (very high), 1.68 to 2.02 m (high), 2.03 to 2.37 m (moderate), 2.38 to 2.72 m (low), and 2.72 to 3.07 m (very low) (Figure 7). Water table weighted 3rd with normalized weight of comparison weightage as 10.7%, with little significance to groundwater potential (Table 3).

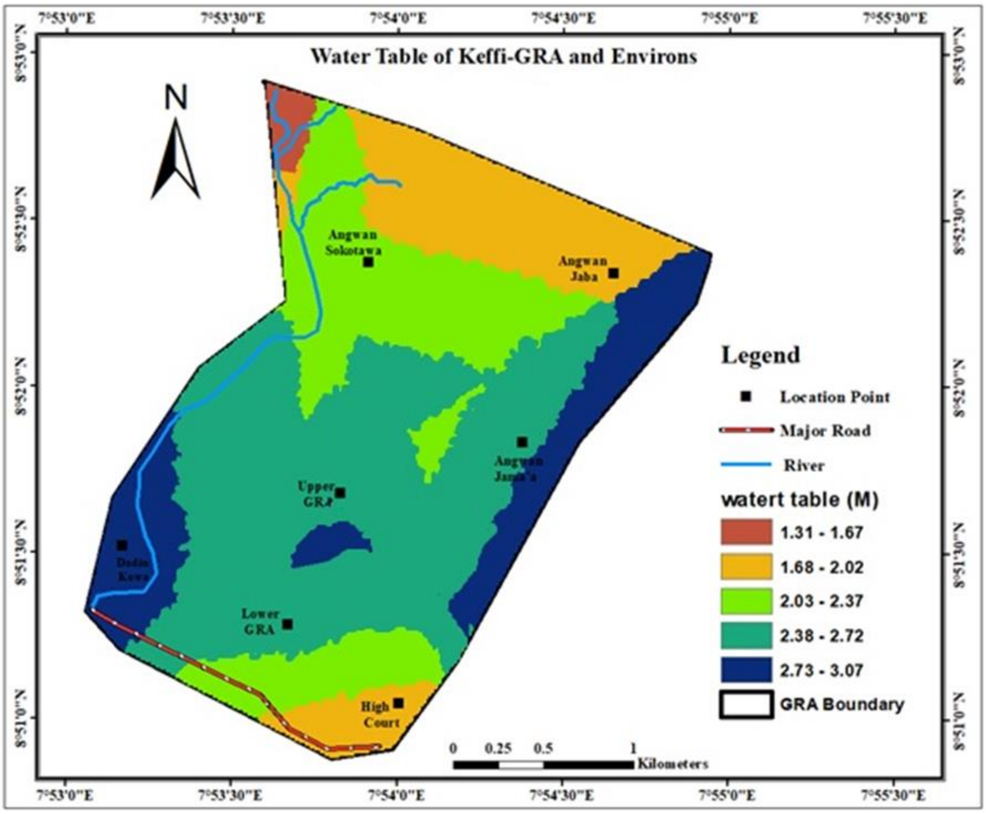

Figure 7: Water table of the study area

Drainage Density

Drainage density refers to the proximity of the stream channel and the extent of the overall length of the stream segment per unit area (Dragičević et al., 2019). Thus, it is the inverse of the permeability of a rock. High drainage density has a negative impact on the rate of water flow and penetration into an aquifer system (Thapa et al., 2017). High permeability of underlying rocks results in low drainage density (Shao et al., 2020). As a result, areas with low drainage density have good groundwater potential (Gnanachan et al., 2018). Drainage density values in this study fall into the following ranges: 19.4 to 54.8 sqkm (very low), 54.9 to 90.1sqkm (low), 90.2 to 126sqkm (moderate), 127sqkm to 161sqkm (high), and 162sqkm to 196sqkm (very high). Drainage density, with a normalized weight of 6.9%, ranked fourth among the parameters selected for this study, with minimal significance on potential (Table 3).

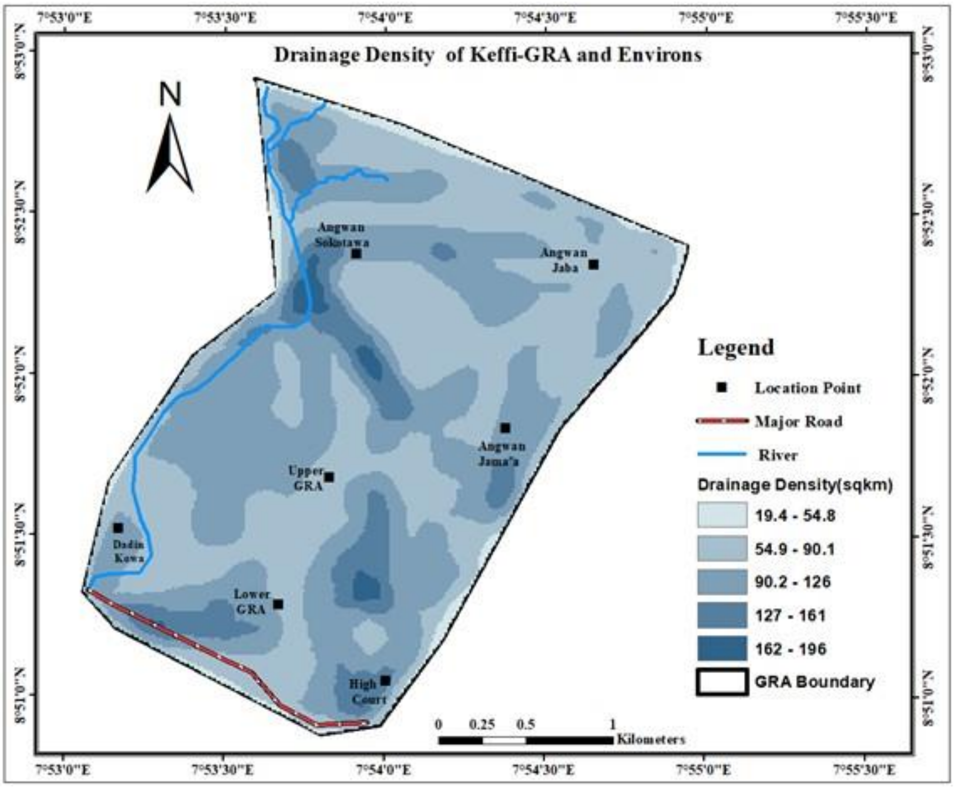

Figure 8: Drainage density of the study area

Elevation

The relationship between elevation height and depth to water is understandable; elevation affects groundwater through slope exposure (Abbaspour et al., 2015). Therefore, higher elevated areas discourage the infiltration process by generating quick surface runoff. Elevation data is vital in determining the water table elevations (Cerlini et al., 2023). The elevation ranges from 279.0 – 288.6m (very high), 288.6 – 294.4m (high), 294.4 – 303.7m (moderate) 303.7 – 316.8m (low) and 316.8 – 326.9m (very low) Among parameters chosen in this study, elevation weighted 5th with normalized weight of 6.8% (Table 3).

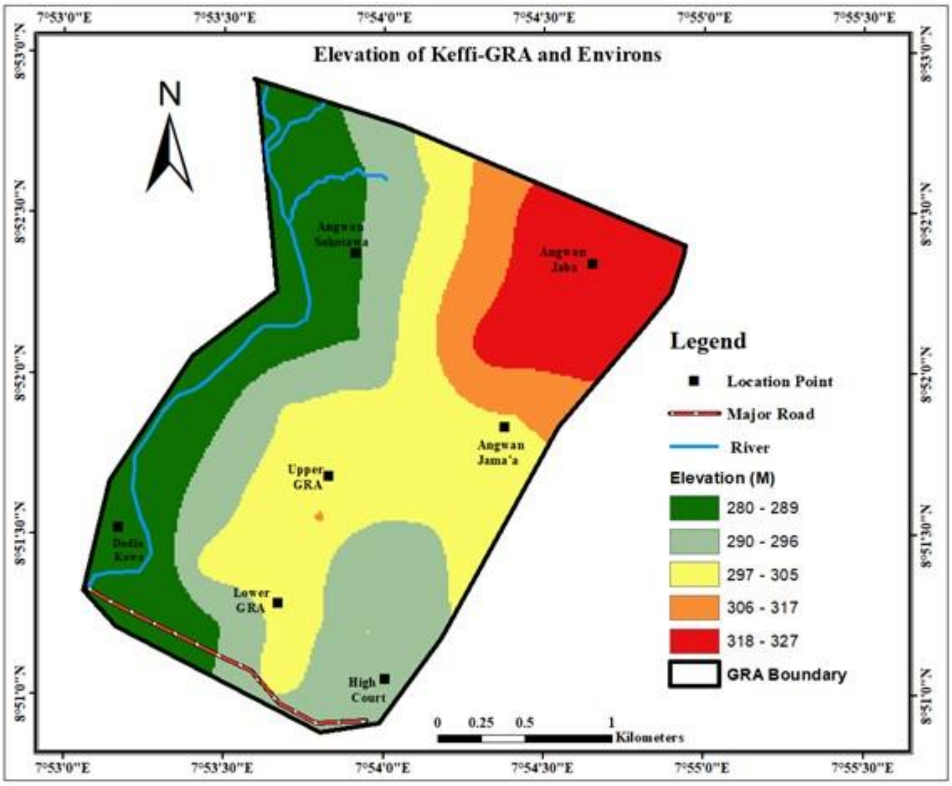

Figure 9: Elevation of the study area

Rainfall

Rainfall is one of the important components that contributes to groundwater recharge (Addisie, 2022). Because infiltrations will naturally replenish the groundwater when we have more precipitation, there will be more water available for surface runoff. From 130 to 140.2 mm (very low), 141 to 150 mm (low), 151 to 160 mm (moderate), 161 to 170 mm (high), and 171 to 180 mm (very high), the rainfall amounts vary. The weighting of these precipitation data was done to account for the impact of perception on groundwater. The region is known for its high rainfall levels, which indicate strong recharging and may lead to favorable groundwater potential zones. Rainfall accounted for 33% of the characteristics selected for this study since it was deemed the second most important factor influencing groundwater potential (Table 3).

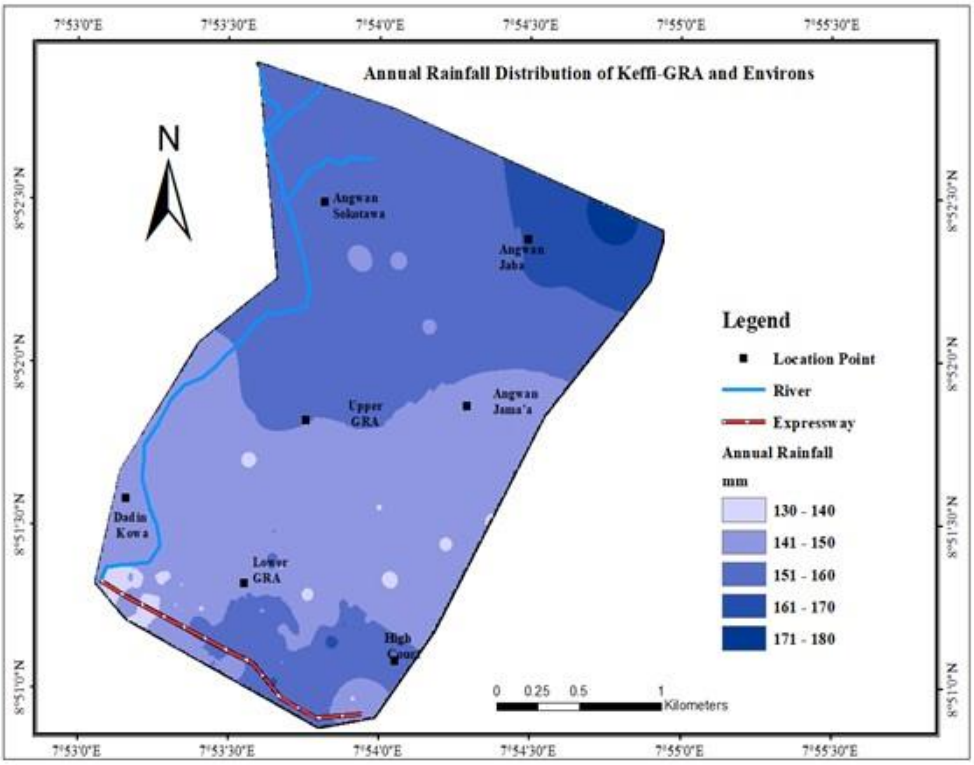

Figure 10: Annual rainfall distribution of the study area
Source: https://Chrsdata.eng.uci.edu/ (2024)

Groundwater potential zone characteristics

The groundwater potential study was integrated from the six thematic map layers and further reclassified into five categories of groundwater potential zones as shown in figure 8. The potential groundwater zones of the study area reveal the following zones, namely, very low, low, moderate, high, and very high. Groundwater potential map of the Keffi GRA and environs (Figure 9), reveals that 466m/0.47km (very low), 5,384m²/5.38km² (low), 3416m²/3.42km² (moderate), 7,357m²/7.36km² (high) and 1,514m²/1.51km² (very high) this also reveals that the percentage of low (29.2%) -high (40.6%) potentiality zone is high, (Angwan Sokotawa, Angwan Jama'a, and Angwan Jaba). The named areas tend to have a moderate reflection of potential due to much concentration of the vegetation use factors that affect groundwater potential; thus, the most dominant land use/land cover factor within the mentioned areas is the presence of high vegetation (sparsed and dense vegetation), which are favorable factors that result in groundwater recharge. Moderate potentiality zones are majorly distributed in the northern and eastern parts (majorly some parts of Upper GRA and Dadinkowa, respectively), covering 18.85 km² (18.85%). The very low potential zone spreads over the western and southern parts; it covers 0.47 km² (2.6%) (some parts of Lower GRA, High Court, and Upper GRA), which could be as a result of the concentration of land use (settlements and built-up); thus, the drilled boreholes in must houses tend to result in more groundwater extraction points leading to flow within the lower GRA, making some boreholes witness some level of depletion within the area.

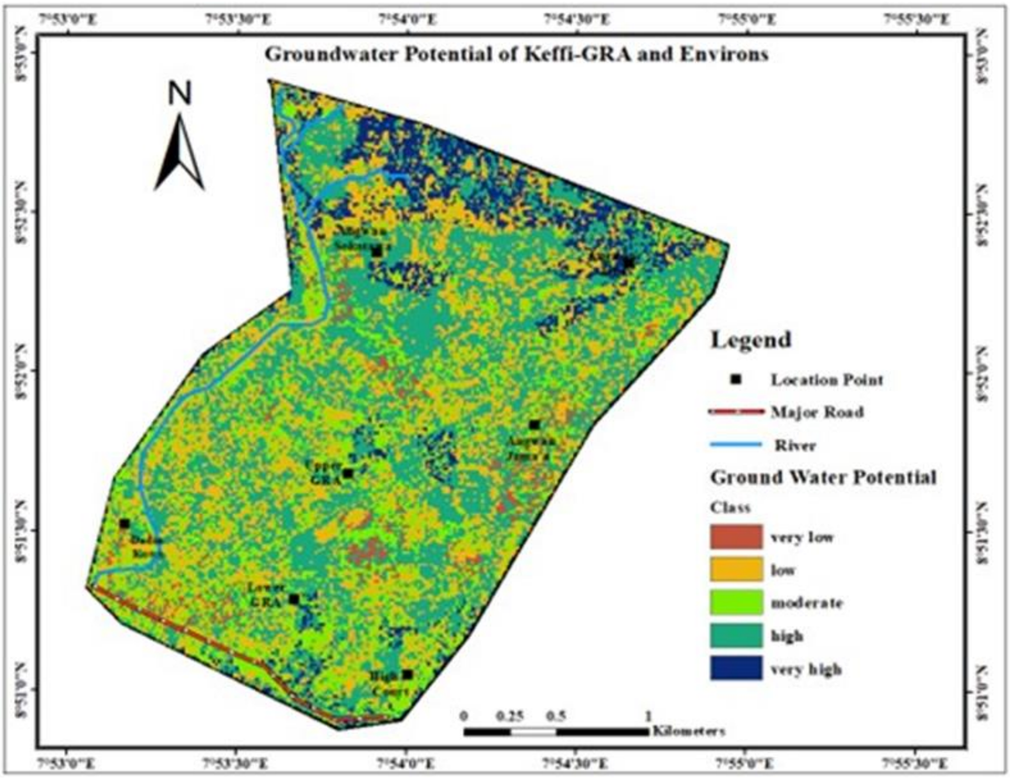

Figure 11: Groundwater potential map of the study area

Therefore, low slope, high rainfall, and good vegetation conditions contribute to the establishment of high potentiality zones, while low potentiality zones are largely caused by constraints to these elements.

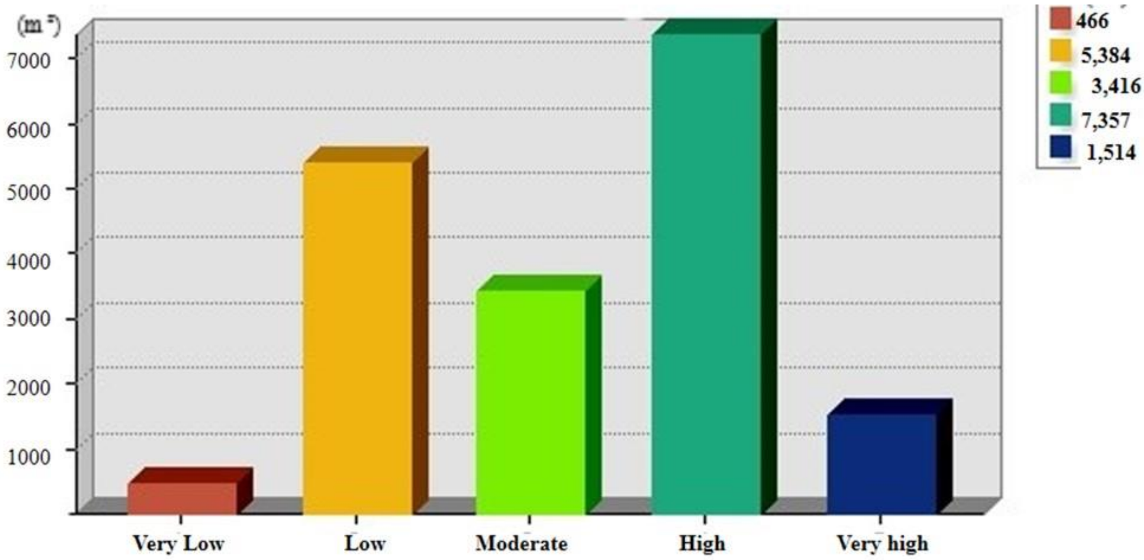

Figure 12: Groundwater potential area coverage bar chart within the study area

Validation of the Groundwater potential zones (GWPZ)

To enhance the accuracy of our findings from the GWPZ, we used validated ground truthing through physical field observations (visual inspections of ground water points, observing vegetation, land surface features, and the presence of water-loving plants), measurements (water table measurements from hand-dug wells), residence/user engagement, and reviewing related literature.

Groundwater Potential (Pairwise Comparison Matrix)

To determine the priority and rank of the themes (Table 3), a pairwise comparison matrix (Table 4) has been created using the AHP technique. The weights assigned to the various themes are shown in Table 4, and the steps taken to obtain the normalized weight are shown in Table 4. Priority, rank, and consistency ratio have been computed for each theme's various classes in the same manner as shown in Tables 4 and 5, and Table 4 displays the consistency ratio for the features.

Table 4: Priorities resulting weights for the criterions based on pairwise comparisons

S/N	Criterions	Priority	Rank	(+)	(-)
1	**Land Use/ Land Cover**	**38.2%**	1	13.0%	13.0%
2	**Slope**	**4.1%**	6	1.6%	1.6%
3	**Water Table**	**10.7%**	3	3.8%	3.8%
4	**Drainage Density**	**6.9%**	4	2.5%	2.5%
5	**Rainfall**	**33.3%**	2	11.0%	11.0%
6	**Elevation**	**6.8%**	5	2.0%	2.0%

Number of Comparisons = 15
Consistency Ration CR = 4.8%

Table 5: The resulting weight based on principal eigen value / vector of the decision matrix

S/N	Criterion	1	2	3	4	5	6
1	**Land Use/ Land Cover**	**1**	**7.00**	**3.00**	**6.00**	**2.00**	**5.00**
2	**Slope**	**0.14**	**1**	**0.25**	**0.33**	**0.14**	**1.00**
3	**Water Table**	**0.33**	**4.00**	**1**	**2.00**	**0.20**	**1.00**
4	**Drainage Density**	**0.17**	**3.00**	**0.50**	**1**	**0.17**	**1,00**
5	**Rainfall**	**0.50**	**7.00**	**5.00**	**6.00**	**1**	**5.00**
6	**Elevation**	**0.20**	**1.00**	**1.00**	**1.00**	**0.20**	**1**

Principal eigen value= 6.303
Eigenvector solution: 5 iterations, delta = 2.0E-8

Consequently, all themes' features maintain a consistency ratio below the 10% threshold. The normalized weights of the various theme classes have been determined similarly and are shown in Table 3. The classes of each theme are reclassified using normalized class weights, resulting in reclassified thematic layers that are integrated into the GIS system.

CONCLUSION

The main objective of this study is to use geospatial techniques such as GIS and remote sensing for the assessment and evaluation of groundwater in Keffi-GRA and environs. The adopted method has proven to be efficient and cost-effective in determining groundwater potential regions. Groundwater potential map (GWPM) has been produced using six (6) thematic map layers, which were generated from satellite images, existing data, and field data (both primary and secondary data). The thematic maps were developed and weights of each important variables controlling groundwater potentials criterions such as annual rainfall, elevation, slope, land use/land cover, drainage density, and water table were assigned using Analytical Hierarchy Process (AHP) model based on their characteristics, this was overlaid and integrated for groundwater potential zone delineation.

The final map for groundwater potential zones was obtained by algebraic summation of these useful parameters multiplied by their effective weights, assigned to each criterion. The result showed a distribution pattern for areas classified as having moderate-high groundwater potential, though with little variation in some parts of the study area. Areas like lower GRA, dadin kowa, and high-court tend to have high groundwater potential zones; this could be as a result of abundant landuse/landcover utilization, especially the abundance of boreholes and other groundwater points within that region; this tends to serve as extraction point clusters from the surrounding locations, while areas like angwan jaba, angwan jama'a, and angwan sokotawa (low abundant landuse/landcover) tend to have moderate groundwater potential zones than the locations within the southern part of the study area. This study was correlated by the already existing groundwater points as a means of revalidation using already existing boreholes (90) both active and non-active and hand-dug wells (20) within the study area which affirms the obtained result by AHP as presented (figure 11), thus coincides with the highlighted findings.

It must be noted that this research is designed for regional application, providing timely insights for groundwater development, management, and exploration.

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