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ASSESSMENT OF GROUNDWATER POTENTIAL ZONE USING ANALYTICAL HIERARCHY PROCESS (AHP), FOR KADUNA NORTH AND SOUTH LGAS

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ABSTRACT
The research aimed to identify groundwater potential zones in the Kaduna South and Kaduna North Local Government Areas of Kaduna State, Nigeria. To achieve this, the study employed a multi-criteria decision-making (MCDM) approach using the analytical hierarchy process (AHP), along with remote sensing and geographic information systems (GIS). Seven thematic layers were analysed to delineate these potential groundwater zones, including land use and land cover (LULC), drainage density, lineament density, geology, slope, rainfall, and elevation. The findings indicated a spatial variation in the distribution of groundwater potential zones (GWPZs) by assessing the relative importance of each thematic layer through AHP and integrating all layers via overlay analysis in a GIS environment. The very high groundwater potential zone comprises 17.24% of the study area, covering approximately 24.43 km². High groundwater potential zones comprise 30.04% of the total area, with an estimated coverage of 42.57 km². Moderate groundwater potential zones account for 31.98% of the total area, covering about 45.32 km², while low groundwater potential zones represent 14.09% of the total area, with an estimated coverage of 19.96 km². Lastly, very low groundwater potential zones constitute 6.65% of the total area, covering around 9.42 km². This study offers valuable insights for decision-making and the development of effective groundwater management strategies.

KEYWORDS: *Groundwater potential, MCDM, AHP, Thematic layers and GWPZs*

1.0 INTRODUCTION

Groundwater is water that exists in the pore spaces and fractures of geologic materials beneath the Earth's surface (Ganapuram *et al.,* 2009), and it is used in the home, agricultural, and industrial environments (Andualem & Demeke, 2019; Janardhana and Reddy, 1998). Most often, groundwater in basement complex terrains is localized and confined to weathered/fracture zones (Ariyo and Adeyemi, 2009).

Many factors, such as lithology, geological structures, soil, lineament characteristics, slope, drainage pattern, land use/cover, and the interactions between these elements, influence

the presence and transport of groundwater in any vicinity (Ganapuram *et al.,* 2009; Solomon & Quiel, 2006; Meijerink, 1996).

Some of the factors responsible for groundwater accumulation and storage (lineament density; drainage density; slope, Land use/land cover and elevation) can be analysed using remote sensing data in a GIS environment (Ganapuram *et al.,* 2009). Using geospatial techniques makes it possible to assess vast amounts of geospatial data and accurately map various natural resources. Numerous researchers worldwide have used remote sensing (RS) and geographical information systems (GIS) to investigate potential zones for groundwater (Shekhar & Pandey, 2015; Sener *et al.* (2005).

The study intends to delineate the groundwater potential of Kaduna North and Kaduna South LGAs using geospatial and Analytical Hierarchy Processes (AHP). With an increasing population, the water demand is rising, and water from the Kaduna State waterboard does not reach everyone within the city. However, groundwater is the alternative source, no wonder, the World Bank, (2022) came up with a topic on World Water Day titled Making the Invisible Visible. The campaign makes the groundwater visible to many people around the world. By forecasting the groundwater potential within Kaduna's north and south local governments, we can ensure efficient use of the water resources within these areas for sustainable development. The findings of the study provide useful information for decision-making processes and for developing appropriate groundwater management strategies.

1.1 Study area description

The study area (Figure 1) is the largest built-up area within Kaduna State with a tilted rectangular block enclosed by two local government areas (Igabi and Chikun local governments area). It is found within the northcentral part of Kaduna state in northwest Nigeria (Figure 1). The rainfall within this environment varies from south to north. Rainfall intensities are high in the south and decrease progressively as one approaches the northern part of the study area Thus, portions of higher precipitation in the study area indicate higher rechargeability of the area's groundwater. Therefore, the study will identify the potential zones of this recharge by combining and analyzing different thematic layers.

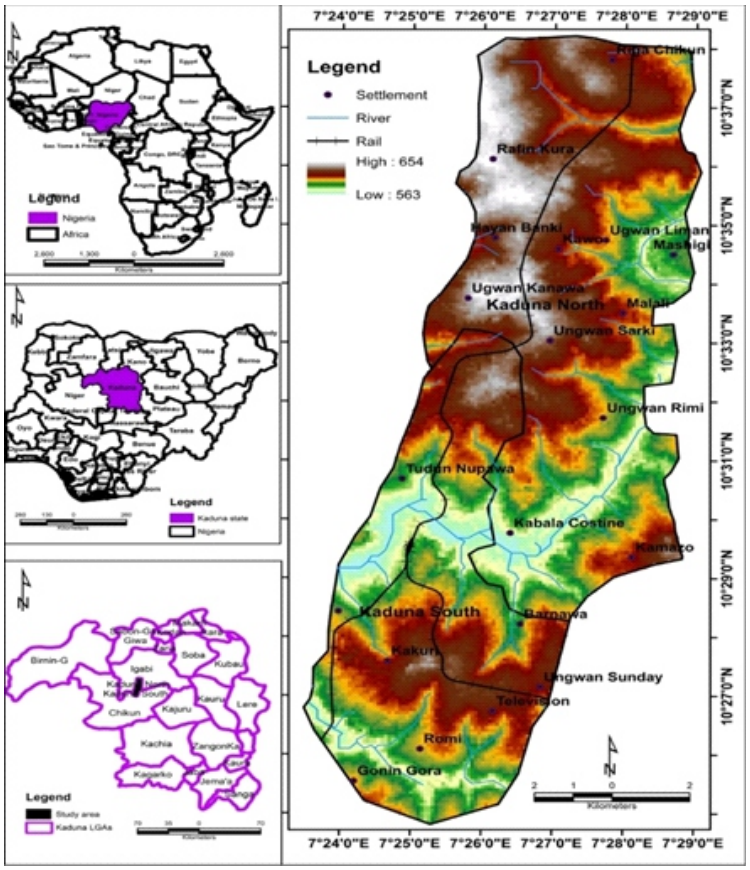

Figure 1: Location map of the study area

2.0 Material and Methods

2.1 Data Source

The data that has been integrated for the evaluation of the groundwater potential zones (GWPZs) of the study area are:

i The use of Landsat-8 Operational Land Imager (OLI) and digital elevation model (DEM)

ii The Geological map of the two local government areas was sourced from the Nigeria Geological Survey Agency (NGSA) Abuja.

iii Rainfall data covering the two local government areas for the year 2023 was obtained from the Nigeria Metrological Agency (NiMet), as summarized in Table 1 below.

Table 1. Data types and sources.

Data type	Source	Spatial resolution	Projection	Application
DEM	USGS	30m x 30m	UTM	Elevation, Slope, Drainage Density
Landsat 8	USGS		UTM	LULC and Lineament Density,
Geological Map	NGSA	Scale 1:100,000	UTM	Geologic map
Rainfall	NIMET, (Abuja)		UTM	Rainfall map

2.2 Methodology

The steps followed in this research work are outlined below. The acquired maps were scanned and digitized using ArcMap version 10.7.1 software to create a digital version of the lithology or geologic map. The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) was employed to generate a drainage density and slope map of the study area, while the Landsat 8 (OLI) image was utilized to create the Land Use/Land Cover (LULC) map and lineament map for the area.

Additionally, rainfall data for the study area was analyzed to produce a map illustrating the variation in rainfall across the area.

The seven maps generated were replicated and organized as thematic raster map layers, which influence the groundwater potential of the area. Each thematic map layer was classified into at least five categories, and weightage was determined using the Analytical Hierarchical Process (AHP), which was then applied to the thematic maps in each layer produced.

The groundwater potential zone map for the research area was created by integrating all seven thematic layers during the final analysis stage of the AHP process, utilizing the weighted overlay tool in ArcGIS Version 10.7.1. This map was developed by combining the total normalized weights of all thematic maps using the equation provided (Malczewski, 1999; Venkateswara and Briz-Kishore, 1991).

$$GWPZ = (SL_wSL_{wi} + ELEV_wELEV_{wi} + LULC_wLULC_{wi} + LD_wLD_{wi} + DD_wDD_{wi} + RFwRF_{wi} + GEO_wGEO_{wi}).$$

Where SL is the Slope, LULC is land use/land cover, LD denotes the Lineament Density DD represent the Drainage Density, RF stands for rainfall, GEO is the Geology, $_w$ stands for the normalised weight of a theme and $_{wi}$ represents the normalised weight of individual classes. The steps followed are displayed in the flowchart (Figure 2).

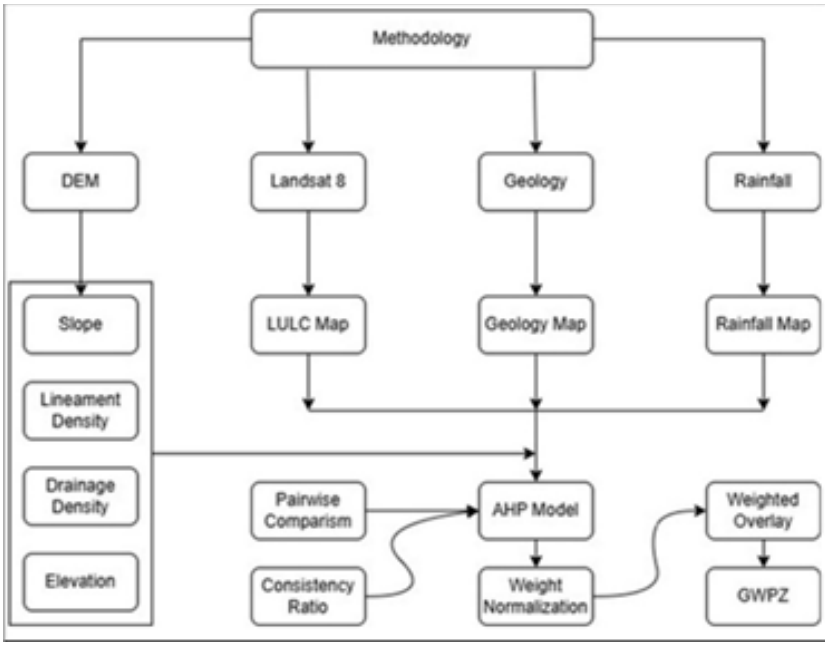

Figure 2: Flow chart for assessing the groundwater potential of the study area

2.3 Analytical Hierarchical Process (AHP)

The most popular and widely used GIS-based technique for defining groundwater potential zones is the multi-criteria decision-making-based analytical hierarchical process (AHP). This process aids in the integration of every theme layer. For this study, seven (7) distinct theme levels were considered. Saaty's AHP was used to normalise the weights of the various themes and the attributes that went along with them. The eigenvector approach was applied to lessen the bias in the allocated weights. A high-weight value represents a highly impactful layer, while a low-weight parameter represents a minimal impact on groundwater potential. The pairwise comparison matrices of the assigned weights of the different thematic maps were computed as displayed in Table 2.

Table 2. The pair-wise comparison matrices table of the different themes

Parameters	Slope	Elev	DD	LULC	LD	Raf	Geo
Slope	1	1/2	1/3	1/4	1/6	1/8	1/9
Elev	2	1	1/3	1/4	1/5	1/6	1/7
DD	3	3	1	1/3	1/4	1/5	1/6
LULC	4	4	3	1	1/3	1/4	1/5
LD	6	5	4	3	1	1/3	1/4
Raf	8	6	5	4	3	1	1/3
Geo	9	7	6	5	4	3	1

The consistency index (CI) of the assigned weights was calculated according to the procedure suggested by Saaty (1980, 1990) while the Consistency Ratio, which indicates the probability that the matrix ratings were randomly generated, was also computed using the values of Random Consistency Index (RI) as shown on Table 3 which is the average value of CI for random matrices using the Saaty scale obtained by Forman (1983, 1990) based on the following relation:

Consistency Index = $(\lambda max - n) / (n - 1)$ 1

Consistency Ratio = CI / RI 2

where n is the number of criteria or factors, λmax is the Maximum eigenvalue, and RI is the Random Consistency Index.

Table 3: Random Consistency Index table from Saaty, (1980)

N	3	4	5	6	7	8	9	10	11	12	13	14	15
Random consistency index	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

CR values should be less than 0.1 for consistent weights otherwise corresponding weights should be re-evaluated to avoid inconsistency the CR for Table 3 is equal to 0.065694166 which implies that our ranks assigned are consistent. The weights for each thematic map were then determined using Saaty's scale of assignment which shows how important each topic is to groundwater availability on a scale of 1 to 9. The weights assigned to the respective thematic maps are presented in Table 5. Geology is ranked highest with a Saaty scale of 9 followed by Rainfall with 8, Lineament Density is ranked 6, Lineament Density is ranked 6 and Land Use/Land Cover and Slope will be ranked 4, 3, 2 and 1 respectively.

Table 4. Normalized Pair-wise Comparison matrix with weights to be assigned to the thematic maps for the potential groundwater delineation.

Parameters	Slope	ELEV	DD	LULC	LD	Raf	Geo	Criteria weight	Assigned weight
SLOPE	0.03	0.02	0.02	0.02	0.02	0.02	0.05	0.03	1
ELEV	0.06	0.04	0.02	0.02	0.02	0.03	0.06	0.04	2
DD	0.09	0.11	0.05	0.02	0.03	0.04	0.08	0.06	3
LULC	0.12	0.15	0.15	0.07	0.04	0.05	0.09	0.10	4
LD	0.18	0.19	0.20	0.22	0.11	0.07	0.11	0.15	6
Raf	0.24	0.23	0.25	0.29	0.34	0.20	0.15	0.24	8
Geo	0.27	0.26	0.31	0.36	0.45	0.59	0.45	0.38	9

, and the summarized weightage and ranking are given to the thematic layers (Table 5).

Table 5: Table showing Factors, weights, and Ranks

Factors	Weight	Rank	Overall
Geology			
Migmatite		3	114
Biotite hornblende granite	38	2	76
Rainfall			
Very high		5	130
High		4	104
Moderate	26	3	78
Low		2	52
Very Low		1	26
Lineament Density			
Very high		5	75
High		4	60
Moderate	15	3	45
Low		2	30
Very Low		1	15
LULC			
Water		5	50
Forest		4	40
Flooded Forest		4	40
Cropland	10	3	30
Built up		1	10
Bare land		2	20
Shrubland		2	20
Drainage Density			
Very high		1	6
High		2	12
Moderate	6	3	18
Low		4	24
Very Low		5	30
Elevation			
Very high		1	4
High		2	8
Moderate	4	3	12
Low		4	16
Very Low		5	20
Slope			
Very high		1	1
High		2	6
Moderate		3	9
Low	3	4	12
Very Low		5	15

3.0 Results and Discussion

3.1 Elevation map

The elevation map of the study area is classified into five classes (Figure 3a). High elevation ranges from 563m to 581.2 m and the lowest elevation class ranges from 635.8m to 654 m. When elevation is high, surface runoff is also high thus contribution to groundwater accumulation will also be low leading to low groundwater potential and vice versa as put forward by (Ojo *et al.,* 2024; Ogungbade *et al.,* 2021; Mitra and Roy, 2023; Kure *et al*., 2019; Alimi *et al.,* 2022). This implies that areas with low elevation will have high groundwater

potential while portions with high elevation will have low groundwater potential within the study area.

3.2 Drainage density map

Figure 3b represents the drainage density map of the study area. The drainage density of the area ranges (0-0.358, 0.358-1.039, 1.039-1.617, 1.617-2.383, 2.383-4.341) km/km^2, and the drainage density is higher in the northern and southern parts of the study area. This implies that High drainage density areas will have high surface runoff, low infiltration rates, and low potential for groundwater recharge (Ojo *et al.,* 2024; Beden *et al.*, 2023; Baghel *et al.,* 2023; Kisiki *et al.,*2022 Ogungbade *et al.,* 2021; Alimi *et al.,* 2022). The higher the drainage density the lower the groundwater potential and vice versa as such low drainage density areas have high rankings, whereas high drainage density areas have lower rankings in this study.

3.3 Slope map

Figure 3c represents the slope map of the area. The slope map of the study area was divided into five slope classes: 0-0.883, 0.883-1.416, 1.416-1.931, 1.931-2.557, and 2.557-4.691, representing very low, low, moderate, high and very high respectively. Also, slope gradient plays a crucial role in how water seeps or percolates into subsurface formations, making it important for mapping groundwater potential. In areas with a steep slope gradient, there tends to be a lot of runoff, whereas flatter terrains with a low slope gradient allow for better groundwater recharge and accumulation. Thus, the gentle slope has high groundwater recharge compared to the steep slopes. This implies that a low slope will have high groundwater potential and vice versa (Ojo *et al.,* 2024; Alimi *et al.,* 2022; Ogungbade *et al.,* 2021). Areas with gentile slopes within the study area are expected to have higher groundwater potential than those areas with steep slopes.

3.4 Rainfall map

Figure 4a represents the rainfall map of the area. The rainfall map was divided into five classes covering the entire area, 1283.66-1294.34 mm, 1294.34-1304.38 mm, 1304.38-1314.42 mm, 1314.42-1324.89 mm, and 1324.89-1338.13 mm. The southern part of the area experiences high rainfall, while the north and southcentral portions have low to very low rainfall, as depicted in (Figure 4a). Rainfall plays a crucial role in determining the rate at which groundwater is recharged. The amount of rainfall that falls across Kaduna State is not uniform, leading to varying levels of groundwater recharge throughout the state. When there is a significant amount of rainfall, the groundwater recharge rate tends to be high, and conversely, a lower amount of rainfall results in reduced recharge (Ojo *et al.,* 2024; Mitra and Roy, 2023; Beden *et al.*, 2023; Baghel *et al.,* 2023; Kisiki *et al.,*2022 Alimi *et al.,* 2022; Akinluyi *et al.,* 2021;). From the rainfall map, rainfall increases as one moves from the south to the north of the study area as such, groundwater potential will increase as we move from the north to the south of the study area. Areas that experienced high rainfall were given higher rankings, whereas those with lower rainfall amounts received lower rankings.

3.5 Land use/Land cover (LULC) map

Key factors influencing groundwater recharge and accumulation, including permeability, soil moisture, and infiltration rate, are significantly affected by land use patterns. Built-up areas tend to hinder infiltration due to a decrease in permeable surfaces (Alimi *et al*., 2022). In contrast, forested areas enhance water infiltration since plant cover can retain moisture and promote percolation (Mitra and Roy, 2023; Allafta *et al.,* 2021; Jothimani *et al.,* 2019). The land use classification for the study area (Figure 4b) identifies seven categories: water, forest,

flooded forest, cropland, Built-up, bare land and shrubland. Water received higher weightings, whereas built-up areas were assigned lower weights.

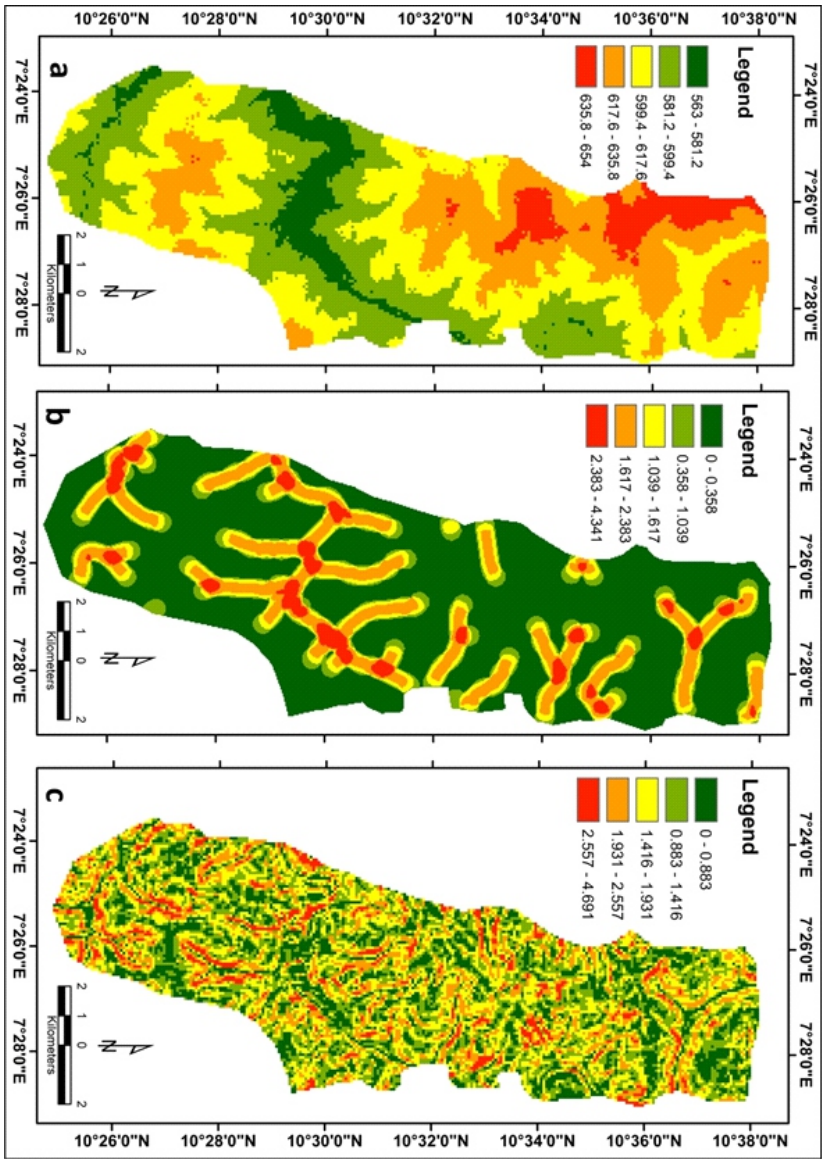

Figure 3: a. elevation map (m), Drainage density map (km/km2) and c. Slope map in degrees

3.6 Geology map

Figure 4c represents the geology of the study area. The study area contains two types of lithological units: Migmatite and biotite-biotite hornblende granite (NGSA, 2009). The geology plays a vital role in determining the presence of groundwater. It greatly influences how water infiltrates the ground and the rate at which groundwater flows, largely due to differences in the porosity and permeability of the underlying aquifer (Alimi et al., 2022). Migmatites exhibit variable permeability because of their heterogeneous composition, which can influence groundwater flow. Their ability to retain moisture is moderate, but this can be improved by the presence of vegetation, especially in areas with abundant plant life and was given a rank of 3. Biotite-biotite hornblende granite can exhibit great permeability if it is highly fractured and was given a rank of 2.

3.7 Lineament Density

Figure 5a illustrates the lineament density map for the study area. It categorizes lineament

density into five intervals: (0.-0.718, 0.718-1.435, 1.435-2.153, 2.153-2.871, 2.871-3.589) km/km2. A lineament refers to a conduit in the rock that acts as a pathway for groundwater flow. It contributes to secondary porosity and serves as a channel for groundwater recharge. The presence of lineaments, along with other favourable conditions, suggests a higher likelihood of groundwater availability. Lineaments are typically formed through tectonic activity and weathering processes. The lineament density map of the area (Figure 5a) highlights regions with varying concentrations of lineaments. Lineaments are relatively sparse in the study area, leading to higher rankings for regions with elevated lineament density and lower rankings for those with reduced lineament density (Ojo et al., 2024; Mitra and Roy, 2023; Beden et al., 2023; Baghel et al., 2023; Alimi et al., 2022; Kisiki et al.,2022; Akinluyi et al., 2021; Ogungbade et al., 2021; Adelana et al., 2008).

4.8 Groundwater Potential Map

The groundwater potential zone map (Figure 5b) revealed a spatial variation in the distribution of groundwater potential within the study area. Based on the map (Figure 5b), and Table 6, the results of this work have made us understand that a very high groundwater potential zone covers 17.24% of the total study area with an estimated area coverage of 24.43 km2.

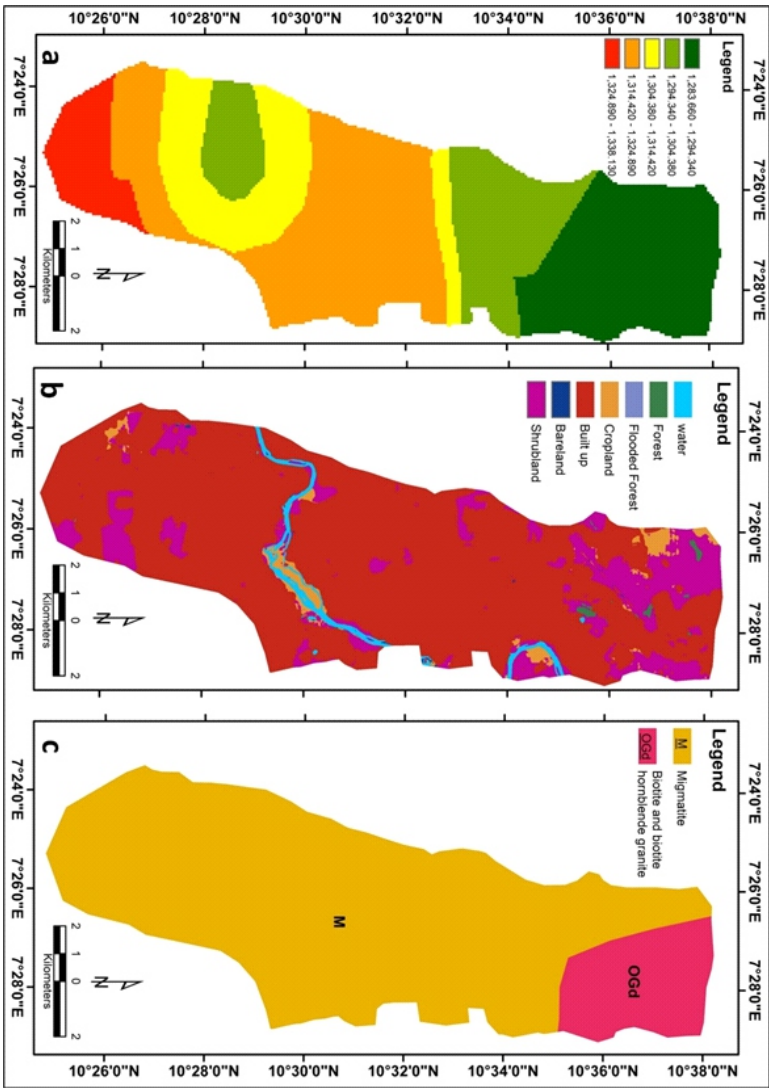

Figure 4: a. Rainfall map (mm), b. LULC map and c. Geologic map

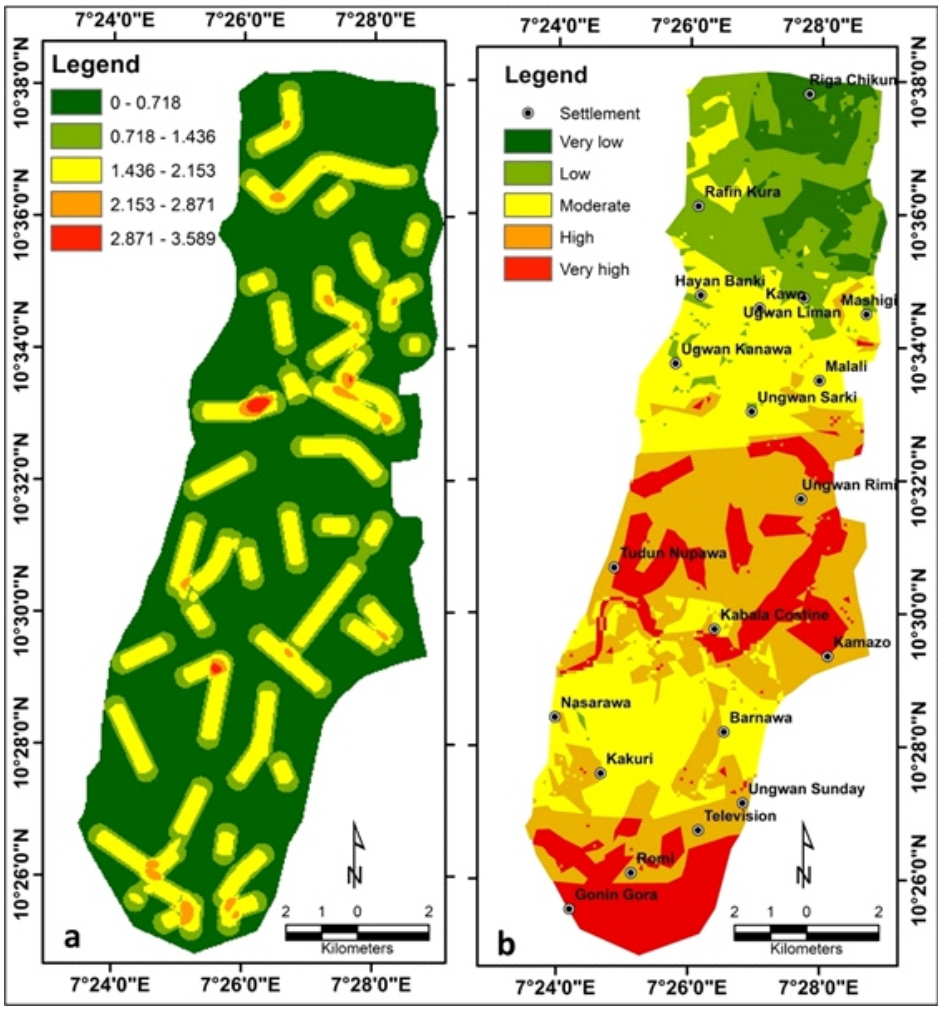

Figure 5: a. Drainage density map (km/km^2) and b. Groundwater potential zone map

Table 7:

S/N	Area(km^2)	Percentage	GWPZ
1	9.42	6.65	Very low
2	19.96	14.09	Low
3	45.32	31.98	Moderate
4	42.57	30.04	High
5	24.43	17.24	Very high

High groundwater potential zones account for 30.04% of the total study area with an estimated area coverage of 42.57 km^2, moderate groundwater potential zones area cover 31.98% of the total study area with an estimated area coverage of 45.32 km^2, low groundwater potential zones portions account for 14.09% of the total study area with an estimated area coverage of 19.96 km^2 and the very-low groundwater potential zones areas account for 6.65% of the total study area with an estimated area coverage of 9.42 km^2. The very high groundwater potential zones are observed in Gonin Gora and environs, Kamazo, Tudun Nupawa and environs and parts of Kabala Costine. High groundwater potential zone areas are observed around Romi, Kakuri, Kamazo, parts of Tudun Nupawa, Cabalar Costine, Ungwan Rimi, Parts of Kakuri and parts of Barnawa. Moderate groundwater potential zones are observed in Hayin Banki, Ungwan Sarki, Malali, Ungwan Liman, Nasarawa, and parts of Kakuri and Barnawa.

4.0 Conclusion

The study's findings indicate that Gonin Gora

and its surrounding areas, along with Kamazo, Tudun Nupawa, and parts of Kabala Costine, are identified as zones with very high groundwater potential. In contrast, Romi, Kakuri, Kamazo, sections of Tudun Nupawa, Cabalar Costine, Ungwan Rimi, parts of Kakuri, and portions of Barnawa are categorized within high groundwater potential zones. These insights are vital for applications in hydrogeology and hydrogeophysics, particularly for groundwater development, where understanding groundwater potential and patterns is crucial. Additionally, the study offers important information for decision-making related to policy formation and the development of effective groundwater management strategies in the Kaduna North and Kaduna South Local Government Areas of Kaduna State.

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