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Assessment of Groundwater Potential of Ovia-North East Local Government Area using GIS, RS, and AHP Methodologies.

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Abstract

Groundwater plays a crucial role in supporting human activities and ecosystems. This study conducted a thorough evaluation of the significant of groundwater potential in the study area using Geographic Information System (GIS) techniques. Various thematic maps, such as those depicting lineament density, drainage density, slope, soil, precipitation, and land use land cover, were created and integrated into the analysis. The Analytic Hierarchy Process (AHP) method was utilized to assign weights to each thematic map, achieving a consistency index of 0.61. By employing weighted overlay analysis, these thematic maps were amalgamated to generate a final groundwater potential map, revealing areas with significant groundwater availability. The results of this study are highly relevant for guiding the selection of potential sites for groundwater exploitation, contributing to a more informed and sustainable management of groundwater resources in the study area. This approach enhances the understanding of groundwater resources and offers a practical framework for future groundwater management strategies.

Keywords: *Groundwater potential, Drainage density, Analytic Hierarchy Process, Geographic Information System, Lineament density.*

1. INTRODUCTION

Groundwater, essential for various purposes, resides in the saturated zone beneath the earth's surface, filling pores in soils and geological formations. Its presence in specific areas is a result of complex interactions among climatic,

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geological, hydrological, physiographic, and ecological factors, rather than chance (Indhulekha *et al*., 2019; Garewal *et al.,* 2019). Although renewable, hard rock environments naturally have limited groundwater (Saraf and Choudhary, 1998; Jhariya *et al.,* 2021). Growing population demands, along with industrial and agricultural practices, are heightening reliance on groundwater due to insufficient surface water. Additionally, untreated waste from these activities is contaminating groundwater reservoirs (Nyaberi *et al.,* 2019). Consequently, research efforts are increasing to understand groundwater resources better and identify high-quality sources suitable for human consumption (Rao and Jugran, 2003; Sarkar *et al*., 2022).

In recent years, the creation of groundwater potential maps has become vital for pinpointing suitable locations for new wells to meet the rising water demand (Naghibi and Moradi, 2017; Tamiru and Wagari, 2021). Thematic representation of groundwater resources improves their utilization and protection (Nguyen *et al.*, 2020; Razavi-Termeh *et al.,* 2019). While traditional land surveying methods were historically used for this purpose, the emergence of Geographic Information System (GIS) and Remote Sensing (RS) technologies has revolutionized the process, enhancing accuracy and speed (Yeh *et al.,* 2016; Mallick *et al*., 2019; Farzin *et al.,* 2021). Integrating remote sensing and GIS offers a cost-effective and efficient approach to identifying groundwater potential zones, enabling comprehensive analysis of diverse datasets for informed decision-making in groundwater management and planning (Singh *et al*., 2017; Kotchoni *et al*., 2019). Many scientists have utilized these technologies to map groundwater potential zones, particularly in situations where traditional surveying methods are impractical (Saraf and Choudhary, 1998; Shaban *et al*., 2006; Ganapuram *et al*., 2009; Shakya *et al*., 2019).

In today's focus on sustainable water resource management, the merging of technology and hydrogeology stands out as a key area for innovative solutions. The complex relationship between human activities and the environment highlights the urgent need for effective tools to assess and manage groundwater resources. This research aims to explore the combined power of Geographical Information System (GIS) and Analytical Hierarchy Process (AHP) as a robust methodology for evaluating groundwater potential. With rapid urbanization, climate change, and growing water demands, there's a heightened need for advanced techniques that offer precise assessments and a comprehensive understanding of the spatial distribution and influencing factors of groundwater potential. GIS, renowned for its spatial analysis capabilities, when paired with AHP, a potent multi-criteria decision-making tool, presents a promising approach to address these pressing challenges. This paper delves into the theoretical foundations and practical applications of GIS and AHP in the context of groundwater potential assessment. As we navigate the complex terrain of water scarcity and environmental degradation, the fusion of GIS and AHP emerges as a beacon of hope.

2. MATERIALS AND METHOD

2.1 Description of study area

The study area, Ovia North-East Local Government Area, is situated in Edo State, which is part of Nigeria's South-South geopolitical zone. Its headquarters is located in the town of Okada. It consists of a number of settlements spread over the latitudes of 5° and 7° 40' N and 5° and 6° 30' E. The region covers an area of 2,301 km². It is a tropical rainforest area characterized by high rainfall, with an average annual precipitation of approximately 2,000 mm. As of 2006, 153,849 people lived in Ovia North-East (National Population Census, 2006). A significant river, the Ovia River, which runs through each community in the LGA, effectively drains the area. The study area map is presented in Figure 1.

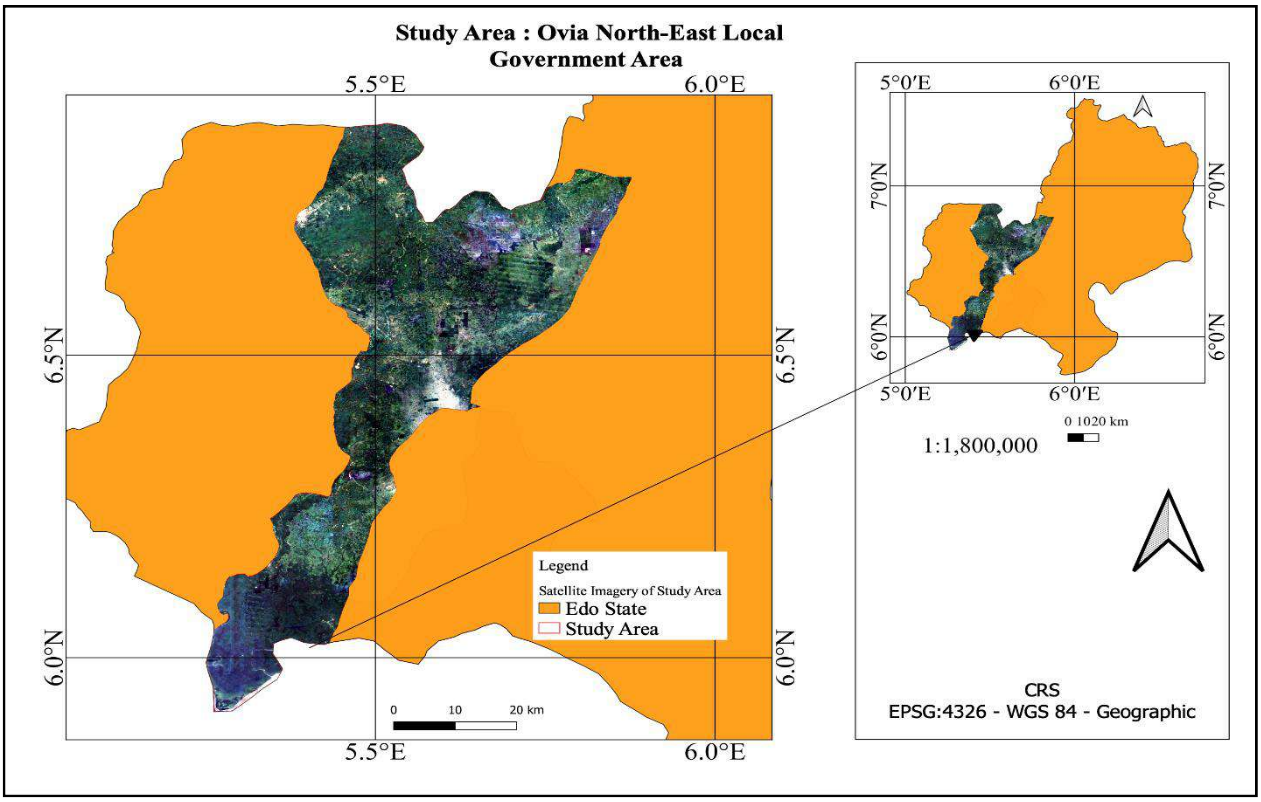

Figure 1: *Study area map.*

2.2 Data acquisition

Both remotely sensed data and field data were collected for this study. Table 1 shows the data type, source and year.

Table 1: *List of data employed for the study*

S/n	Data / Scale	Type	Source /Date
1.	Landsat 8 Satellite imagery (30m Resolution)	Remotely sensed	USGS (2018)
2.	SRTM Data (30m DEM Resolution)	Remotely sensed	USGS (2018)
3.	Topographical map 1:100,000	Digital Copy	Federal Survey (2018)
4.	Geological Map (1:500,000)	Digital copy	Nigerian Geological survey Agency (2018)
5.	FAO Soil Data	Remotely Sensed	FAO (2018)
6.	LULC Data	Remotely Sensed	ESA (2020)
7.	Rainfall Data	40 years Annual Data	1978 – 2018

The Landsat 8 data products were downloaded from the USGS EROS Center, processed, and imported into the ArcMap software environment. The Landsat Program has provided over 40 years of calibrated medium spatial resolution data of the Earth's surface to a broad and varied user community, with Landsat 8 being the latest in a continuous series of land remote sensing satellites. Additionally, the NASA Shuttle Radar Topographic Mission (SRTM) has been instrumental in providing digital elevation data (DEMs) for more than 80% of the Earth's surface, accessible through downloads from the USGS EROS Center. Complementary topographical and geological maps were acquired from the Office of the Surveyor General and the Nigerian Geological Survey Agency, respectively.

2.3 Data processing

All acquired satellite images were projected to the UTM coordinate system (WGS84 UTM31N). Using a specified boundary extent as the "Area of Interest," all acquired data was clipped using the Clip tool in the ArcMap environment to match the specified area.

ArcMap 10.6.1 served as the primary software for map analysis in this study. The study region's shapefile, previously prepared in ArcGIS, was imported after acquiring the Digital Elevation Model (DEM) from the United States Geological Survey (USGS) website. The DEM was clipped to the required shape using the "Clip Raster" function and subsequently reclassified into five groups; Very High, High, Moderate, Low, and Very Low using the "Reclassify" function. Using the clip tool in ArcMap, the geo-referenced geological map was clipped to the study extent, and the geological units underlying the study area were digitized along with the settlement and geographical features from the topographical map to create a final geological map of the study area. The lineament extraction process was conducted using PCI Geomatica v16 software on Landsat 8 image bands B and 5 (near-infrared band) to enhance and visualize lineament features. After contrast enhancement and various image filtering techniques, the lineament extraction algorithm in PCI Geomatica was applied to generate the lineament map. The orientation of the lineaments was interpreted using a rose diagram and compared with the general fault direction of the study area. The extracted lineament map was overlaid onto an existing geological map using ArcMap's overlay analysis functionality, and a lineament density map was created to visualize the distribution and density of lineaments across the study area. Using the SRTM 10m DEM, a hillshade/slope map was created in ArcMap, and contour lines were generated from the DEM using the 'Create Contour' tool to inform us of the flat and steep sections of the study area. Additionally, drainage lines were digitized from the hillshade map generated from the DEM, and a final drainage, slope, and contour map was produced in ArcMap.

2.4 Estimating the weight of influence of thematic data

The influence weight for each factor was statistically computed using the Analytical Hierarchy Process (AHP). The initial step in designing the AHP involved defining the criteria and sub-criteria. To establish a significance scale ranging from one to nine for the parameters, Saaty's scheme was utilized, as outlined in Table 2. This approach facilitated the conversion of linguistic judgments into numerical values.

To generate the AHP matrix required for computing the percentage weight of influence for each groundwater influencing factor, a review of previous related research was conducted to determine the relative importance of each criterion. The results of this review are presented in Table 3.

Table 2: *Saaty Summary Table*

Sig. Strength	Explanation	Comments
1	Equal significance	Two elements contribute equally to the objective
3	Moderate significance	Judgment slightly favours one element over another
5	Strong significance	Judgment strongly favours one element over another

7	Very strong significance	Judgment strongly favours one element over another, its dominance is demonstrated by experience
9	Maximum significance	The dominance of one element over another is demonstrated and absolute
2, 4, 6, 8	Can be used to express intermediate values	

Table 3: *Superiority of selected criterion*

Pairwise Comparison of Maps	**Relative Importance**	**Relative Magnitude**
Precipitation vs Geology	Precipitation > Geology	3
Precipitation vs Slope	Precipitation > Slope	3
Precipitation vs Drainage Density	Precipitation > Drainage Density	3
Precipitation vs LULC	Precipitation > LULC	5
Precipitation vs Lineament Density	Precipitation > Lineament Density	5
Precipitation vs Soil	Precipitation > Soil	7
Geology vs Slope	Geology > Slope	3
Geology vs Drainage Density	Geology > Drainage Density	3
Geology vs LULC	Geology > LULC	5
Geology vs Lineament Density	Geology > Lineament Density	5
Geology vs Soil	Geology > Soil	5
Slope vs Drainage Density	Slope = Drainage Density	1
Slope vs LULC	Slope > LULC	3

Slope vs Lineament Density	Slope > Lineament Density	3
Slope vs Soil	Slope > Soil	5
Drainage Density vs LULC	Drainage Density = LULC	1
Drainage Density vs Lineament Density	Drainage Density > Lineament Density	2
Drainage Density vs Soil	Drainage Density > Soil	3
LULC vs Lineament Density	LULC = Lineament Density	1
LULC vs Soil	LULC > Soil	3
Lineament Density vs Soil	Lineament Density = Soil	1

To validate the AHP results, the index of consistency was employed. The principal eigenvalue (λ_{max}) is a function of the matrix divergence from consistency. In other words, a pairwise matrix is considered consistent only when λ_{max} equal or more than the number of the layers examined. The index of consistency was estimated using the mass balance equation proposed by Saaty, (1980) as follows

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

Where; λ_{max} denotes the principal eigenvalue, and n represent the number of parameters. For a 3 by 3 matrix, the consistency index is less than 0.05. For a 4 by 4 matrix, it is 0.09 while for large matrices, it is 0.1. If it matches, then the pairwise comparison is said to be consistent and the calculated weight of influence is said to be valid.

2.5 Generation of ground water potential zone map using GIS

In this study, seven thematic maps; Lineament, Geology, Drainage Density, Soil, Precipitation, Land Use/Land Cover, and Slope were evaluated for their impact on groundwater potential in the study area. These maps were integrated using weighted overlay analysis, a straightforward method for combining multi-class maps. In this process, each factor was assigned specific weights and ranks. The weights were statistically determined using the Analytical Hierarchy Process (AHP). To establish the desirability level of each attribute, measurement ranges were employed to rank each factor on a scale of 1 to 5, with the weights expressed as percentages. The overall assessment process is illustrated in the flowchart shown in Figure 2.

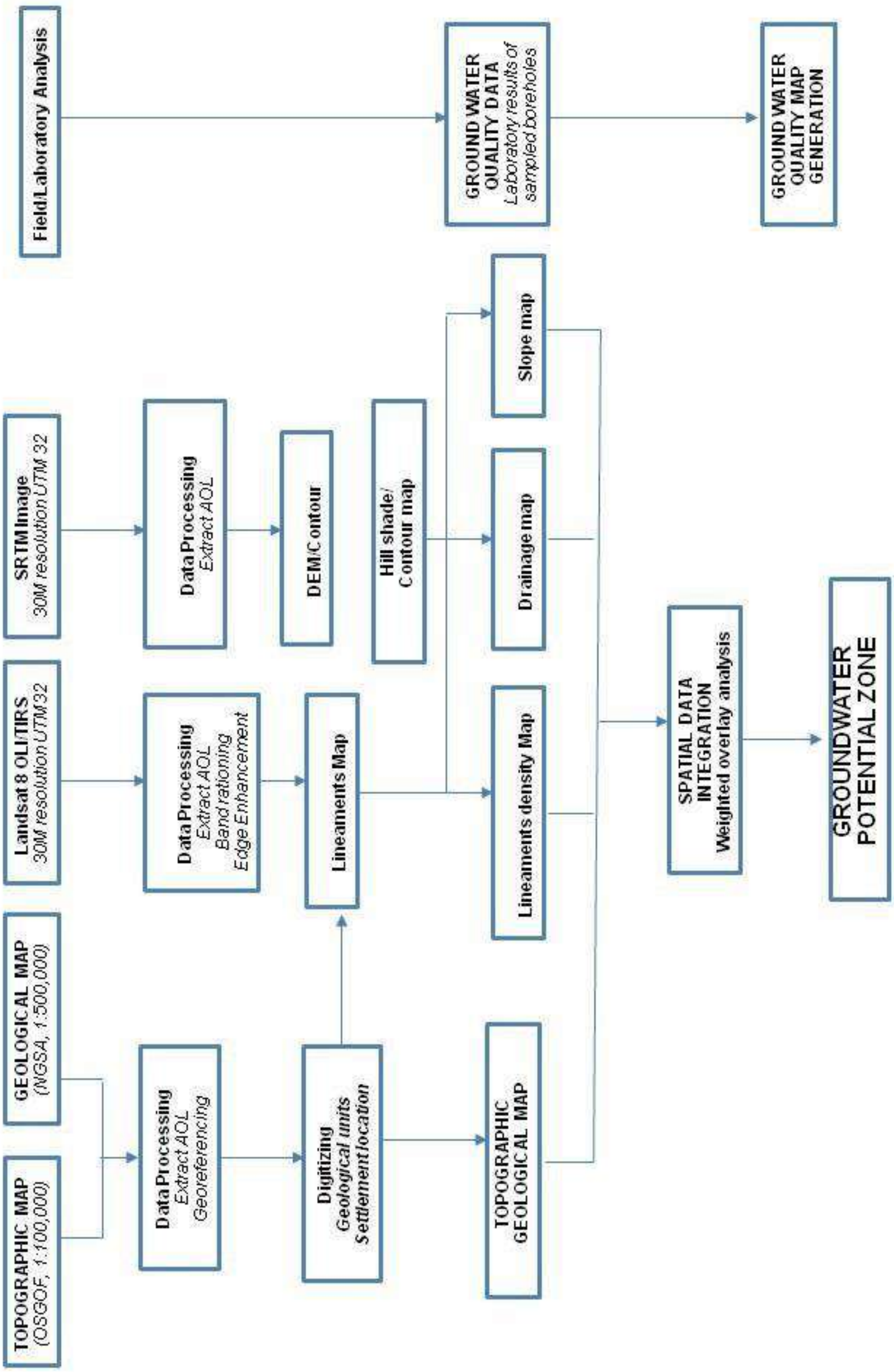

Figure 2: *Layout for delineating groundwater potential zone*

3. RESULT AND DISCUSSION

The shapefile and digital elevation model (DEM) of the study area is presented in Figures 3 and 4 respectively.

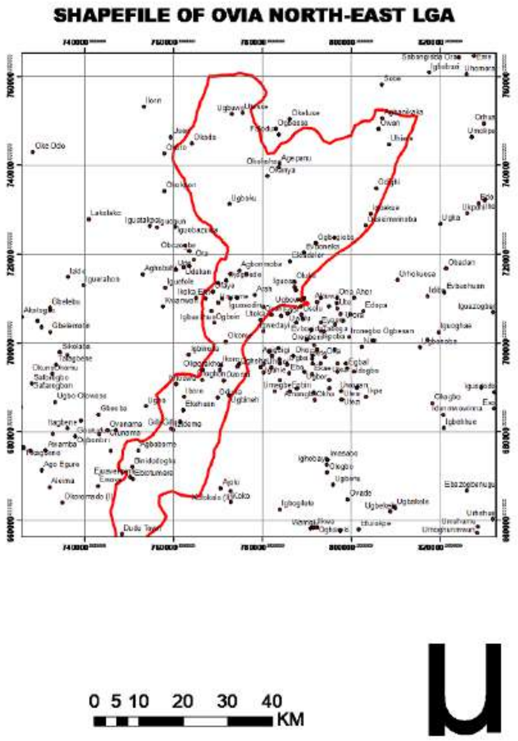

Figure 3: *Study Area shapefile*

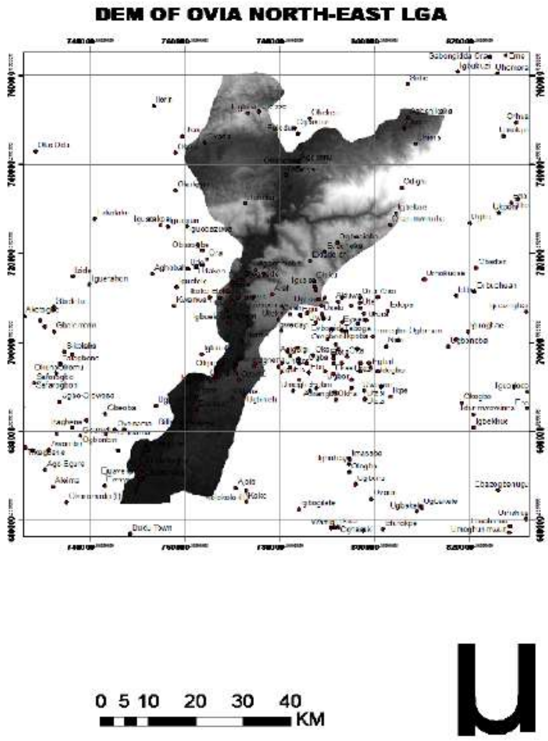

Figure 4: *DEM of the study area*

A geology map is a crucial component in assessing groundwater potential due to its significant influence on the distribution, movement, and availability of groundwater within a given area. The geological characteristics of an area play a pivotal role in determining how water flows through the subsurface and interacts with rock and soil formations. The geology map of the study area is presented in Figure 5a while the reclassified geology map is presented in Figure 5b.

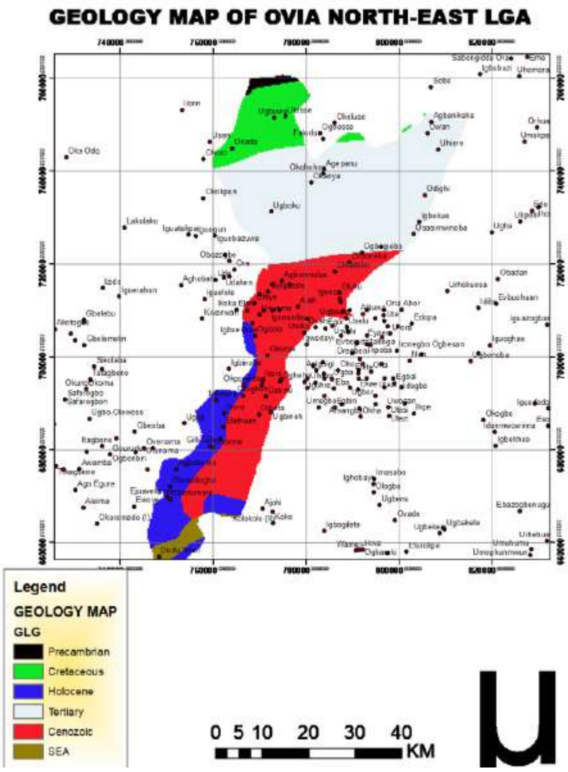

Figure 5a: *Geological map of the study area*

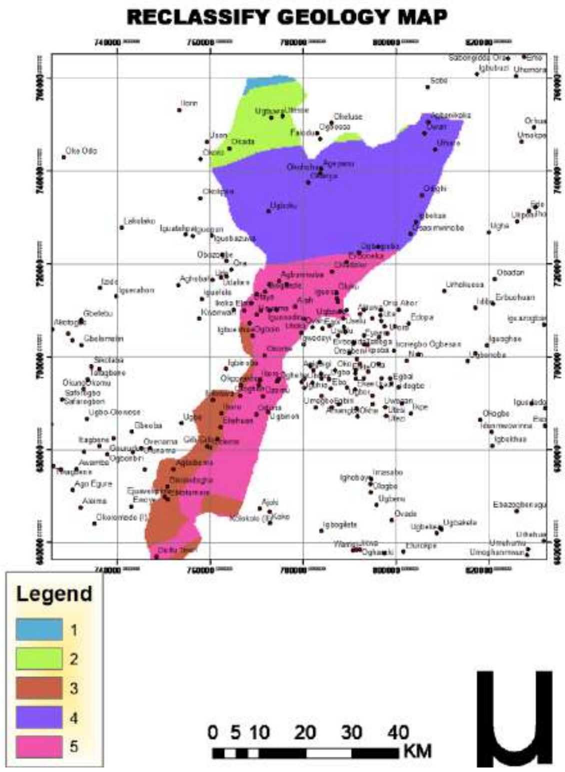

Figure 5b: *Reclassified geological map*

There are six predominant rock types in the study area with tertiary rock occupying the largest area coverage and covering towns such as Okokpon, Ugboku, Owan, Uhiere, Odighi, Agepanu, Okohohon and Okanya. The cretaceous rock covers towns such as Okoro, Okada, Ugbuwe and Utesse. SEA has lower coverage with Precambrian rock having the least area coverage. Table 4 shows the breakdown of area covered by each geological unit in the study area.

Table 4: *Area Size of Geological Units*

Geological Unit	AREA (Km²)	Area covered in Percentage (%)
Cretaceous	2916	9.68
Cenozoic	9041	30.01
Holocene	3839	12.74
SEA	608	2.02
Tertiary	13462	44.69
Precambrian	259	0.86

The groundwater potential varies significantly across different geological formations. Cretaceous rocks, known for their diverse sedimentary formations like sandstones and limestones, generally exhibit good groundwater potential, particularly in porous and permeable layers, while shales tend to limit groundwater flow. Cenozoic rocks, spanning the last 66 million years, include highly permeable unconsolidated sediments and some volcanic rocks, making them significant aquifers in many regions. Holocene deposits, formed in the last 11,700 years, often consist of sands, gravels, silts, and clays, providing high groundwater potential due to their high permeability and rapid recharge rates. Sub-Economic Aquifers (SEA) typically have limited groundwater potential due to low permeability, limited recharge, or poor water quality, making them less viable for large-scale extraction. Tertiary rocks, ranging from 66 to 2.6 million years ago, vary widely in groundwater potential, with sedimentary formations like sandstones and conglomerates generally offering good resources, while volcanic rocks can also be significant depending on their fracture patterns. Precambrian rocks, older than 541 million years, are usually crystalline and metamorphic with low primary porosity and permeability, but groundwater can be found in fractures and weathered zones, providing limited yet vital resources in some regions. Understanding these variations is essential for effective water resource management, particularly in areas where groundwater is crucial for agricultural, industrial, and domestic use.

Lineament density of an area can indirectly reveal the groundwater potential since the presence of lineament usually denotes a permeable zone. Areas with high lineament density are good for groundwater potential zones. Figure 6a shows the lineament density map of the study area while the reclassified lineament density map is presented in Figure 6b.

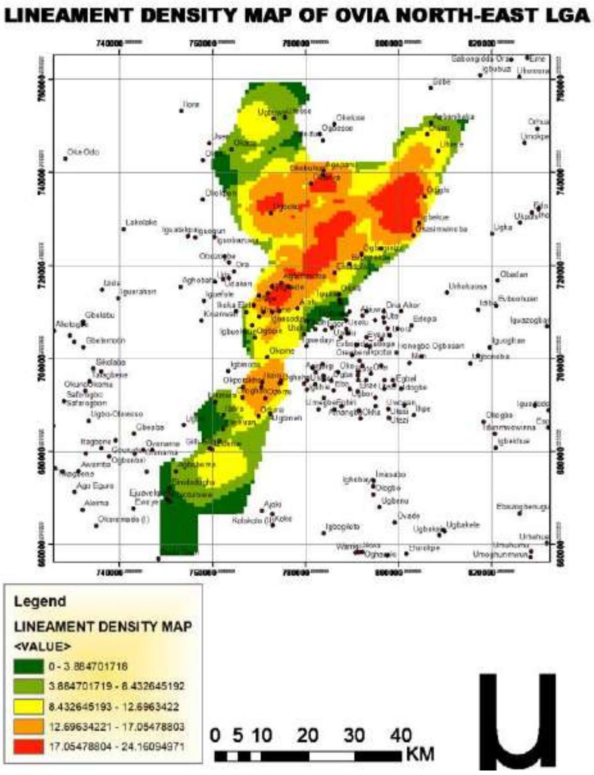

Figure 6a: *Lineament density map*

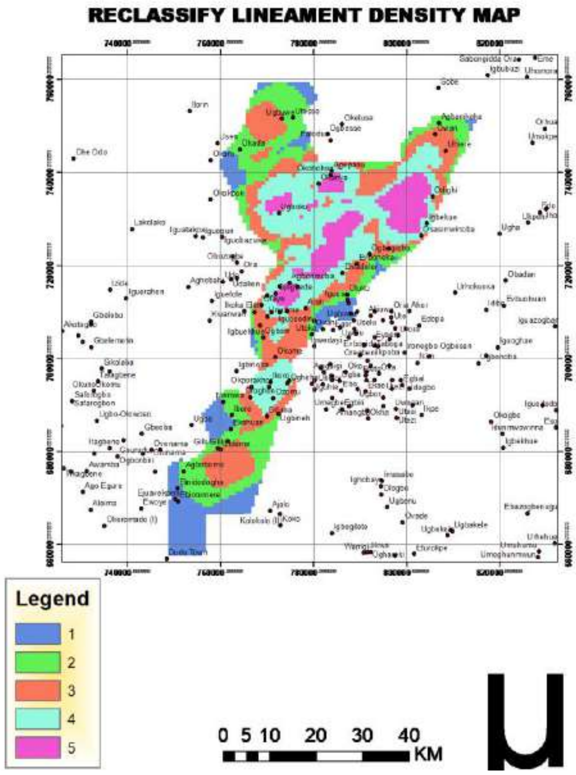

Figure 6b: *Reclassified lineament density*

A lineament map plays a significant role in groundwater potential analysis, especially in regions where geological structures and fractures have a significant influence on groundwater occurrence and movement. Lineaments are linear features on the Earth's surface that represent faults, fractures, and other geological discontinuities. These features can have a direct impact on groundwater flow and storage. The lineament density was done by the line density in ArcGIS tools and classified in to five categories as presented in Table 5.

Table 5: *Lineament Density of study area showing rank*

Factor	*Value (Km/Km^2)*	*Rank*	*Rank in words*	*Weight*
Lineament Density	0 – 3.88	1	Very low	
	3.88 - 8.43	2	Low	
	8.43 – 12.70	3	Moderate	
	12.70 – 17.05	4	High	
	17.05 – 24.16	5	Very High	

The Lineament density map shows that high density lineaments occur in the central region of the study area comprising of Ugboku, Okanya, Ogbonmoba, Ofaye, Ogighi and Igbekue. Lower density lineaments are seen in Iboro, Ekenhuan, Nikrowa and Agbabome. High density lineament indicates high porosity and percolation of water into basement rocks.

Drainage density is a measure of how extensively a network of stream channels and rivers is developed within a given area. It is typically expressed as the total length of all streams and rivers per unit area. In groundwater potential analysis, drainage density can provide valuable insights into the subsurface hydrogeological conditions and contribute to understanding groundwater potential. The drainage density map of the study area is presented in Figure 7a while the reclassified drainage density map is presented in Figure 7b.

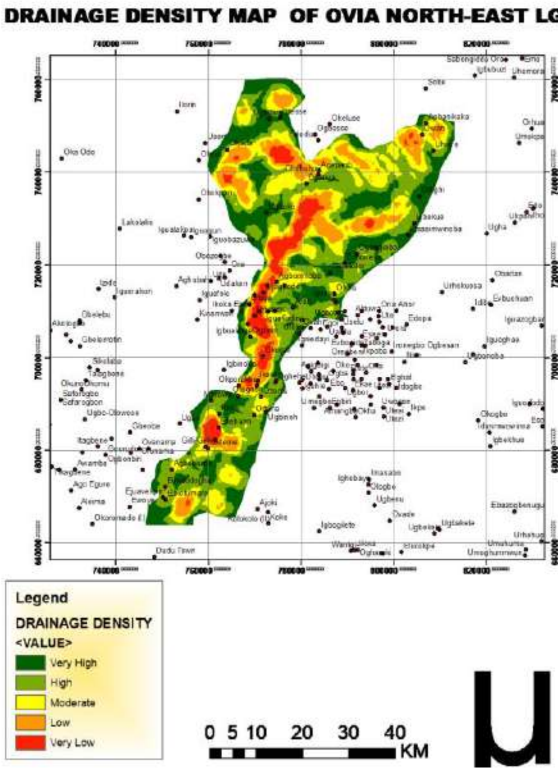

Figure 7a: *Drainage density map*

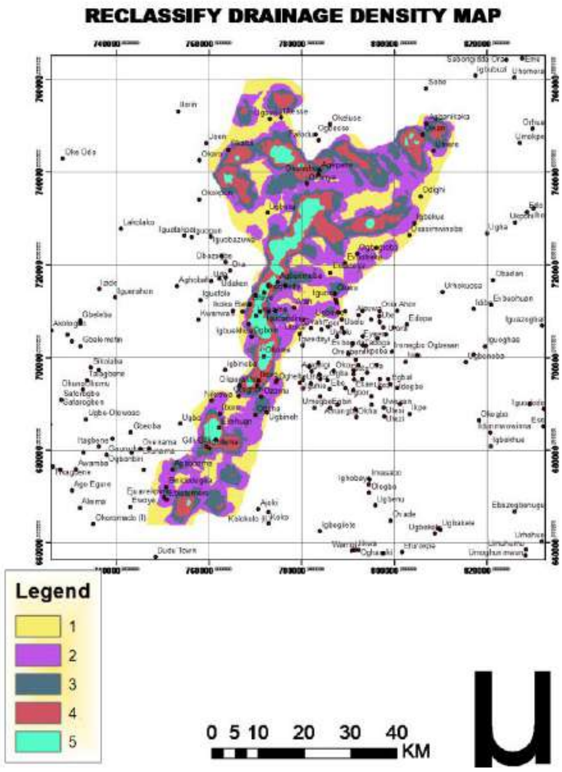

Figure 7b: *Reclassified drainage density map*

The drainage density map shows that the areas with high drainage densities include towns such as Ibillo, Makeke, Ekpesa, Ososo, Egbetua, Okpe, Egbune Ugbo, Ogbodo, Eshiawa, Egene. Areas with moderate drainage density include Ojirami, Gbagere, Igbigele, Megori, Ile-Aro while areas with low drainage density includes areas such as Aiyeteju, Enwan, Ojirami-Oke, Ojirami-Ogbodo, Ogbe and Igarra.

A slope map is an important factor in groundwater potential analysis as it can significantly influence the movement and distribution of groundwater within a specific area. The slope of the land surface affects various hydrological processes, including infiltration, runoff, and groundwater recharge. The slope map of the study area is presented in Figure 8a while the reclassified slope map is presented in Figure 8b.

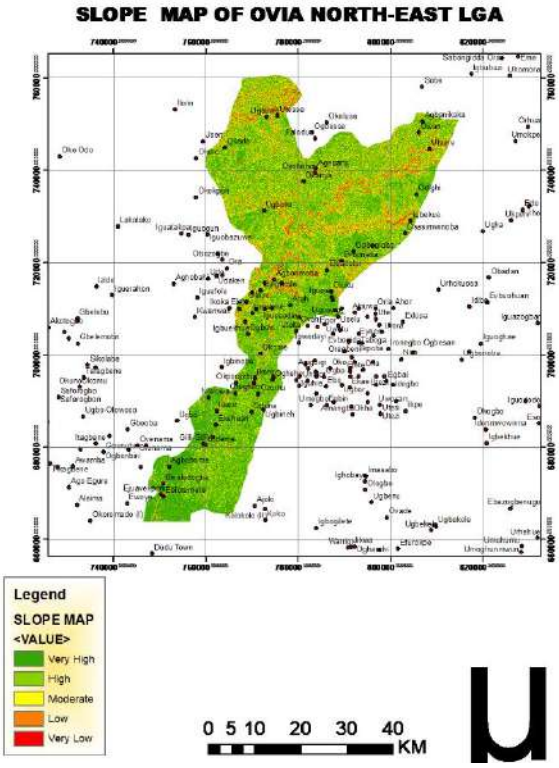

Figure 8a: *Slope map of the study area*

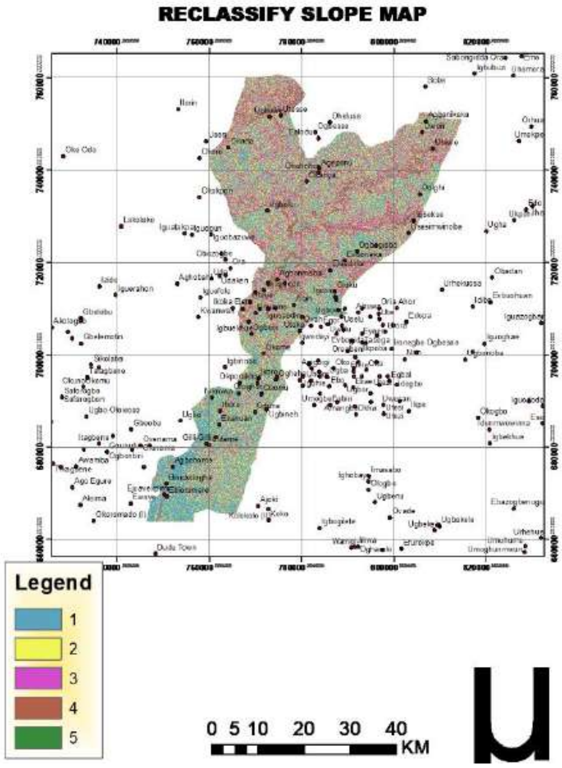

Figure 8b: *Reclassified slope map*

The slope subclasses have been broken in to 5 (five); 0-5% group are the lowest slope angles, while 26-55% group are the highest slope angles. The highest slope angles are recorded on the sides of ridges, which are dominant in the central and eastern region of the study area. Table 6 shows the ranked values for the various slope subclasses.

Table 6: *Slope ranges and ranked values*

Factor	*Value (%)*	*Classification*	*Rank*	*Rank in words*	*Weight*
slope	0 - 5	Flat	5	Very High	
	6 - 10	Gentle Slope	4	High	
	11 - 15	Moderate Slope	3	Moderate	
	16 - 25	High Slope	2	Low	
	>26	Steep	1	Very Low	

Soil map is highly relevant in groundwater potential analysis as soil characteristics play a significant role in determining how water interacts with the subsurface and how groundwater is stored and transported. Soils directly affect the infiltration rate, water-holding capacity, and permeability of the ground, which in turn impact groundwater behaviour. The soil map of the study area is presented in Figure 9a while the reclassified soil map is presented in Figure 9b.

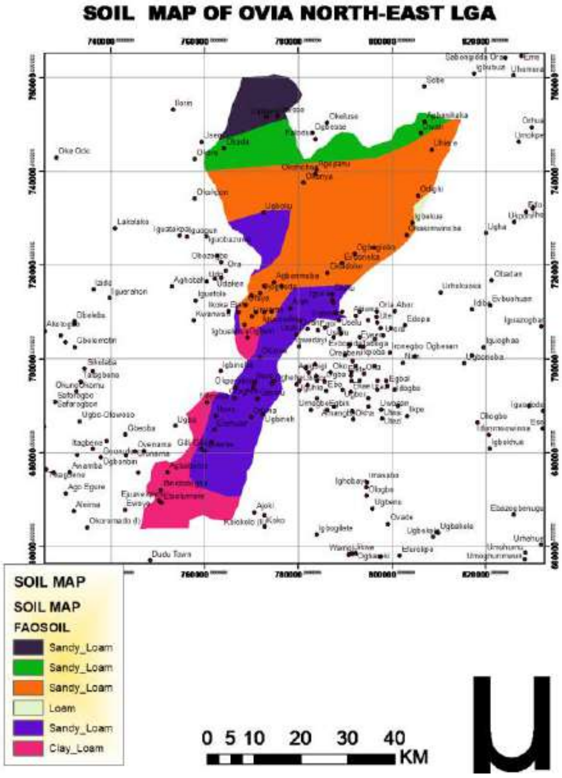

Figure 9a: *Soil map of the study area*

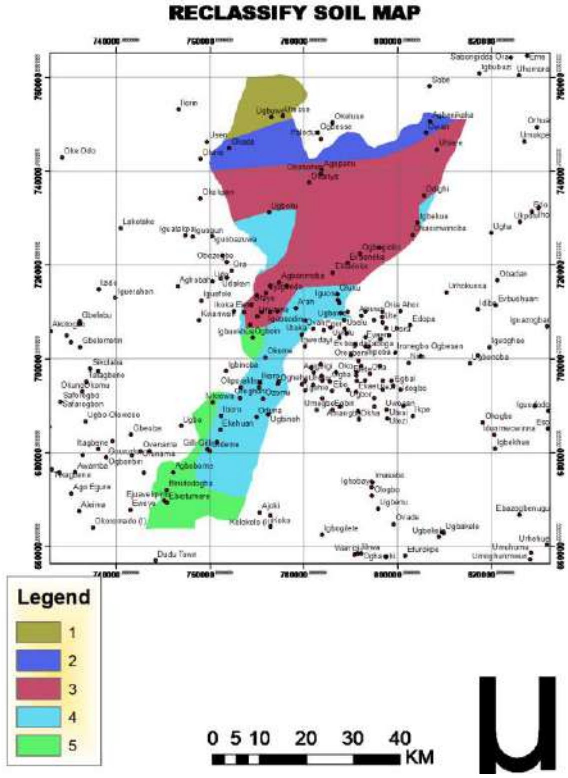

Figure 9b: *Reclassified soil map*

Table 7 shows the breakdown of area covered by each soil class in the study area.

Table 7: *Area Size of soil class*

Geological Unit	COUNT	FAOSOIL
Sandy_Loam	149167	Nd15-1a
Sandy_Loam	273810	Nd20-1a
Sandy_Loam	1067831	Nd17-1a
Loam	10344	Nd18
Sandy_Loam	604551	Nd21
Clay_Loam	270745	G2-2/3a

Precipitation map is important in groundwater potential analysis because it provides essential information about the amount and distribution of rainfall in a specific area. Precipitation is the primary source of water that replenishes groundwater aquifers through the process of recharge. The precipitation map of the study area is presented in Figure 10a while the reclassified precipitation map is presented in Figure 10b.

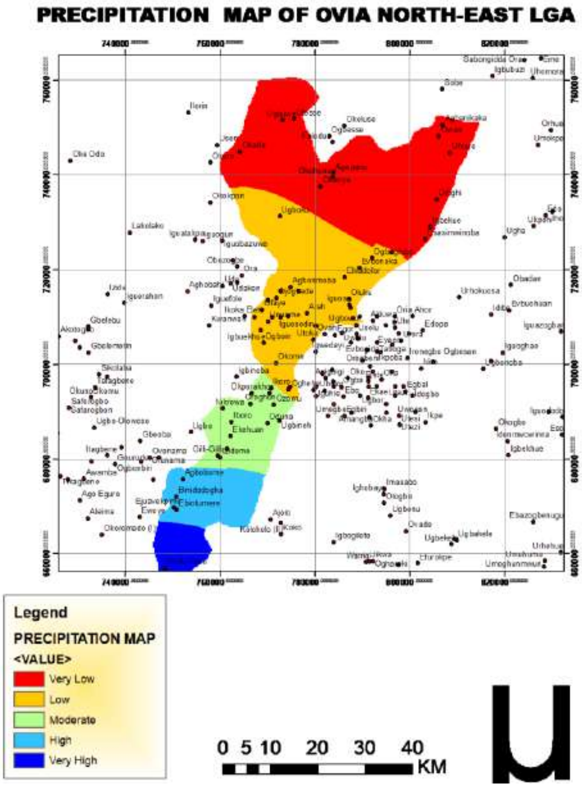

Figure 10a: *Precipitation map*

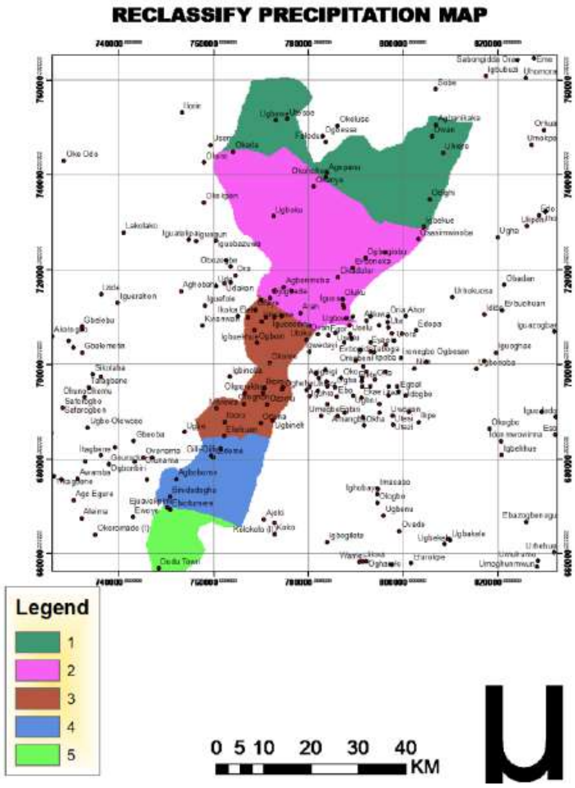

Figure 10b: *Reclassified precipitation map*

The land use land cover map of the study area is presented in Figure 11a while the reclassified land use land cover map is presented in Figure 11b.

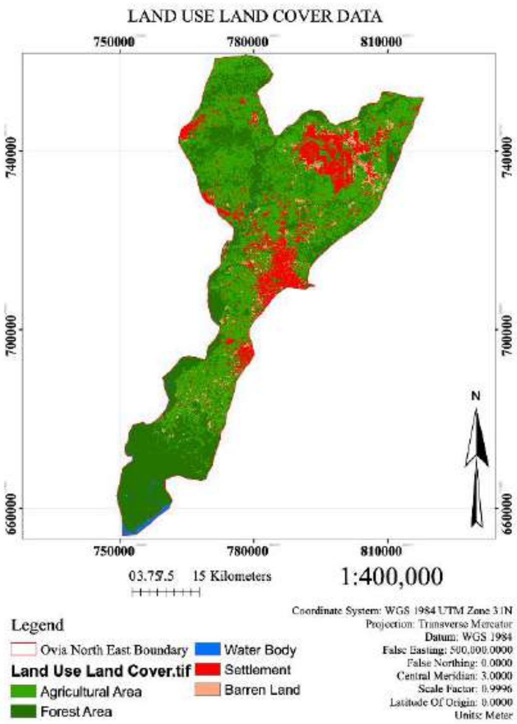

Figure 11a: *Land use land cover map*

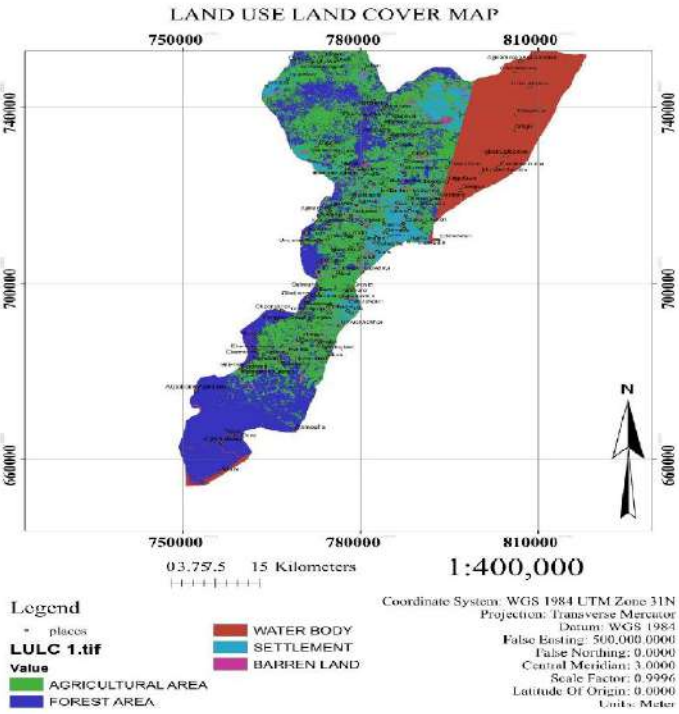

Figure 11a: *Reclassified land use land cover map*

To estimate the percentage weight of influence for each thematic map, analytical hierarchy process (AHP) was employed and result is presented in Table 8.

Table 8: *Percentage of Influence of groundwater potential indicators*

Criteria	Percentage (%)
Precipitation	30
Geology	24
Slope	15
Soil	13
Drainage Density	8
Lineament Density	6
Land use land cover	4

IC = 0.061; RC = 1.25%

With an estimated index of consistency of 0.061 as observed in Table 6, it was concluded that the pairwise comparison is consistent and the calculated weight of influence is valid. Hence, the final groundwater potential map was generated using weighted overlay and result is presented in Figure 12.

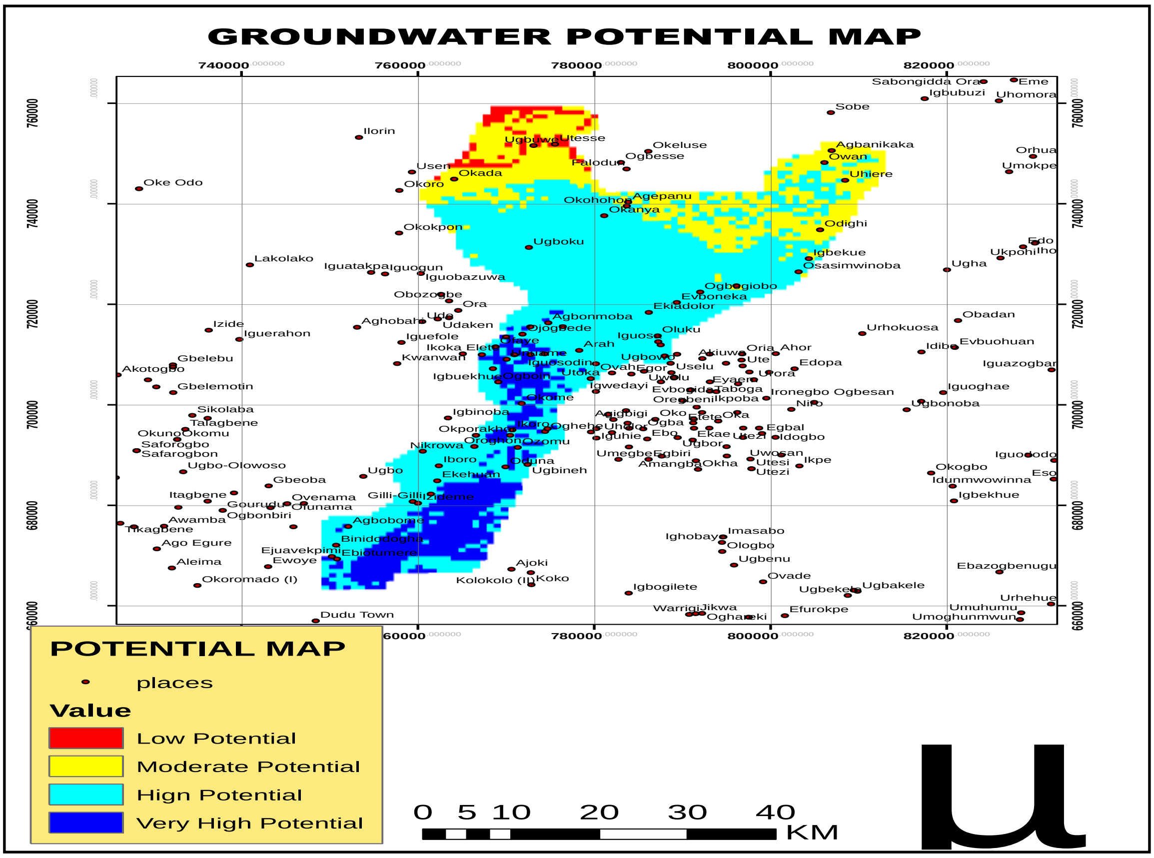

Figure 12: *Groundwater petential map of the study area*

The areas marked blue in the groundwater potential map represent areas with high potential for groundwater.

4. CONCLUSION

The search for groundwater is a monumental endeavor, demanding substantial financial investment and manpower. Investigative research aimed at identifying potential groundwater zones is crucial, given the indispensable role water plays in sustaining life. The integrated use of remote sensing and Geographic Information System (GIS) technologies for identifying groundwater potential zones offers a cost-effective and time-efficient solution. This approach provides a robust platform for the comprehensive analysis of diverse datasets, thereby facilitating informed decision-making in groundwater management and planning. In this study, significant efforts have been directed towards generating a detailed groundwater potential map for the study area. This map is of immense value not only to local communities but also to governmental bodies, private entities, and non-governmental organizations committed to ensuring access to clean and potable water resources. The findings of this research underscore the importance of advanced technological tools in enhancing our understanding and management of groundwater resources, thereby contributing to sustainable water resource development and planning. As global challenges such as urbanization, climate change, and increasing water demand intensify, the methodologies employed in this study can serve as a model for other regions seeking to optimize their groundwater resources.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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