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INVESTIGATION OF GROUNDWATER POTENTIAL UTILIZING GEOSPATIAL TECHNIQUES IN OWERRI, NIGERIA

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Abstract: This study used geospatial approaches to examine the potential of groundwater within the study area. Analytic Hierarchy Process (AHP) method was used combining various parameters including Rainfall (39.5%), Geology (23.5%), Slope (12.5%), Drainage Density (8.0%), LULC (6.1%), Lineament Density (5.4%), and Soil Type (5.0%) for an integrated geospatial analysis to assess the potential for groundwater in the study area. Pairwise comparisons were used to assess the relative importance of each parameter. AHP determined these weights after the pairwise matrices were completed. These weights show the relative importance of the themes when assessing the study area's potential for applications such as land-use planning or natural resource management. The AHP technique allows for the systematic evaluation and ranking of alternatives based on a variety of criteria. A groundwater potential index (GPI) map was created by combining all of these thematic maps and classifying the research area into three zones: poor (0.001 %), fair (41.092 %) good (58.686 %), and excellent (0.261 %) groundwater potential areas. The findings showed significant groundwater potential in regions with higher lineament density, low to average slope, and suitable land use and land cover. The weighted overlay strategy was reliable, according to the consistency ratio (CR) analysis of 0.043884. This work shows the importance of an integrated RS and GIS analysis for determining groundwater potential. The results help identify locations with higher groundwater potential and enable sustainable use of groundwater resources.

Keywords: *Geospatial Modeling; Groundwater Exploration; Hydrogeology; Spatial Analysis; Water Resources Management*

1. INTRODUCTION

It is impossible to exaggerate the significance of water as a resource for life on Earth. Yisa and Jimoh's (2010) research indicates that the world's population increases and industrialization are to blame for the rising demand for freshwater. Nigeria, which has recently witnessed a tremendous pace of industrialization and population increase, is no exception to this trend. As a result, groundwater has gained popularity as a source of water due to its broad occurrence and availability as well as the fact that it possesses high-quality components that make it suitable for drinking (Agbasi et al. 2019). According to Sander (2007), many Nigerians are now obliged to drink well water due to a lack of freshwater supplies. Over half of the world's population relies on groundwater for sustenance, hence this tendency is not specific to Nigeria. Since groundwater is one of the cleanest types of water found in nature, it is a perfect source for supplying the total water requirement in rural and semi-rural areas (Abdulrazzaq et al. 2020). Particularly in rural areas, it is regarded as the main supply of water for human activities, including drinking (Fasunwon, 2008).

Exploring and using alternative water sources, such as groundwater, is crucial given the rising demand for freshwater (Agbasi et al. 2019). Communities lacking access to sufficient quantities of fresh water can benefit from the stable and safe drinking water that can be obtained from groundwater (Aboyeji, 2013). Groundwater is an important component of the earth's water cycle, which refers to the natural circulation of water in the ecosystem (Opara et al. 2020; Akaolisa et al. 2022a). Given that it accounts for around 30% of the world's freshwater supplies, groundwater is regarded as one of the most important sources of freshwater on Earth (Akaolisa et al. 2022b). It supports agriculture, manufacturing, and a variety of other human endeavours and is a very important resource for economic growth and human well-being.

Despite its significance, groundwater is in danger because of several human activities that can contaminate it. Some of these activities include the excessive use of fertilizers and pesticides in agriculture, the disposal of chemical waste in water bodies from industrial activities, and other forms of pollution (Akaolisa et al. 2022c) Groundwater quality is deteriorating rapidly, posing a significant risk to human health and the environment. Accurately assessing the groundwater resources and the characteristics of the aquifers is critical for addressing various hydrogeological and hydrological problems in the study area (Mogaji, 2016; Mogaji et al. 2021). This geospatial approach provides a comprehensive assessment of the aquifer's vulnerability to contamination and enables the implementation of appropriate management strategies to ensure its long-term sustainability. Groundwater Potential (GWP) mapping assesses aquifer vulnerability by identifying places with significant water reserves, understanding hydrogeological conditions, mapping recharge zones, and monitoring land use consequences.

Contamination of groundwater occurs when there is an adverse change in its quality, rendering it unsuitable for human consumption and other environmental needs (Kumar et al. 2015; Akinlalu et al. 2021). Although groundwater is naturally attenuated, it is nevertheless susceptible to contamination, especially in regions where pollution-producing human activity is prevalent (Akinlalu et al. 2021). Unfortunately, this vital resource has not gotten enough care and protection, which has resulted in numerous instances of quality degradation. Therefore, it is crucial to put policies into place that aim to avoid groundwater contamination, such as limiting the use of pesticides in agriculture and reining in industrial activities that produce pollutants.

Groundwater found in holes and fractures of geological formations is protected from evaporation and contamination, making it appropriate for a variety of uses (Agidi et al. 2022). Hydro-geophysical methods like electrical resistivity, magnetics, gravity, electromagnetics, seismic, and remote sensing are used to determine groundwater depth. Gravity and magnetics are good for mapping large-scale features, while seismic methods are more accurate for locating subterranean aquifers and fractured rock structures (Agbasi and Etuk, 2016). In this study, groundwater potential in several areas of Owerri, Southeast Nigeria, was examined using geospatial approaches.

Owerri, a city in the southeast of Nigeria, is one such region that needs in-depth examination. Imo State's capital, Owerri, is a rapidly expanding urban area with a population of more than a million. Due to the city's expanding population and burgeoning economic activity, groundwater resources are essential to supplying the city with the water it requires. The purpose of this study is to use geospatial approaches to examine the potential for groundwater in specific areas in Owerri, Southeast Nigeria.

2. STUDY AREA

The Owerri study area is situated in Imo State, one of the states in Nigeria. Imo State is headquartered in Owerri, a city in the southeast of the nation. According to Figure 1, the city is located between latitudes 5°28'N and 5°33'N and longitudes 7°00'E and 7°07'E. Two important rivers border Owerri on either side. The Otamiri River forms its eastern border, and the Nworie River forms its western border. These rivers influence the local hydrology by serving as a supply of water for diverse uses and sculpting the terrain (Ibe and Sowa, 2002).

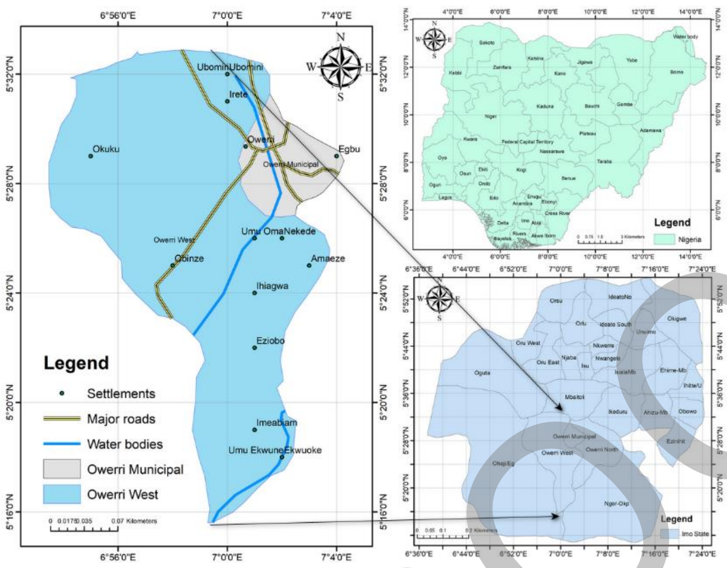

Figure 1
Map of the study area and Imo State, Nigeria

The sedimentary rocks of the Benue Trough, which have a considerable impact on the geology and geography of the area, are intricately linked to the geology of Owerri, Imo State as shown in Figure 2. A significant geological feature in Nigeria is the Benue Trough, which is a component of the wider West African Rift System, a tectonic structure that extends through numerous West African nations (Ibe and Sowa, 2002).

A linear depression with a length of about 1,000 kilometres and a maximum width of 150 kilometres, the Benue Trough. It crosses several Nigerian states, notably Imo State, where Owerri is situated. This geological formation resulted from tectonic activities connected to continental rifting during the Early Cretaceous period, from 130 to 100 million years ago (Ibe and Sowa, 2002). Sedimentary rocks predominate in the geological composition of the Benue Trough. The ecosystems in which these rocks were deposited throughout millions of years included marine, lacustrine (lake), and fluvial (river) settings.

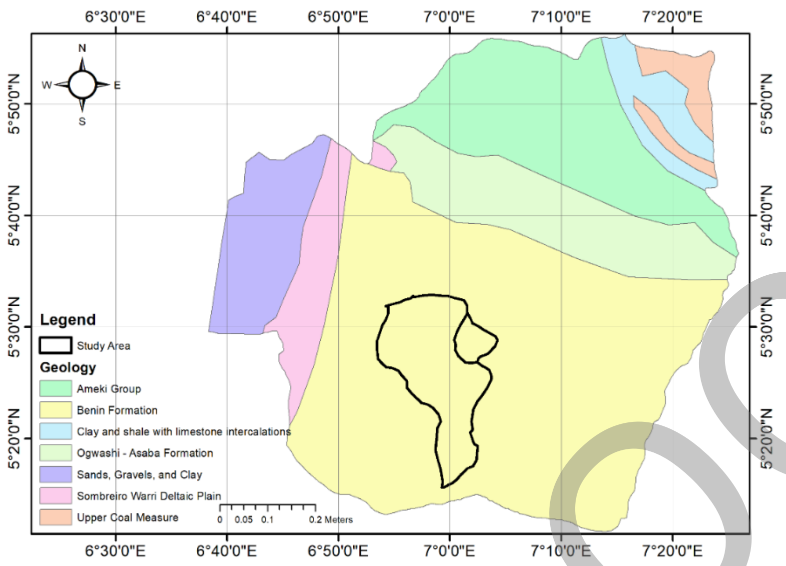

Figure 2
Geology map of the study area and Imo State

The tectonic forces affecting the area are what led to the development of these structures. While folds are curved or bending rock layers brought about by compression, faults are cracks in the rocks along which movement has taken place. The topography and the distribution of rock units in the region have been impacted by these structural elements, resulting in elevational variations and the production of geological features like hills and valleys (Ibe and Sowa, 2002). Understanding the geology of Owerri offers important insights into the region's geological past and natural resources. It provides hints about the potential for mineral deposits and other valuable resources as well as aids geologists in their understanding of the processes that produced the landscape over millions of years (Ibe and Sowa, 2002).

3. METHODOLOGY

3.1. Data Sources in Groundwater Potential Assessment

The geospatial analysis in this study made use of the Digital Elevation Model (DEM) and Satellite Shuttle Radar Topography Mission (SRTM) data. The global reference system-2 served as the reference framework as the satellite took photographs of the Earth over a 16-day repetition cycle (Aladeboyeje et al. 2021). The scene's covering area was roughly 170 km in the North-South direction and 183 km in the East-West direction. ArcGIS 10.8 software was used to build and integrate numerous thematic layers required for finding pertinent groundwater potential areas and carrying out groundwater research.

3.2. Materials

Different remote sensing platforms can give DEM data, depending on the subject. This study used aerial LiDAR to acquire DEM data. LiDAR laser pulses return to the sensor after hitting the ground. Using the laser pulse's return time, ground distance is calculated millions of times to create a dense topographical point cloud (Sharma et al. 2010).

Table 1

Data Sources and Resolutions for Environmental Parameters in the Study Area

Parameter	Data Source	Resolution
Digital Elevation Model (DEM)	Aerial LiDAR	Vertical: 5 cm, Horizontal: 1 m
Lineament Maps	ALOSPALSAR	Automated feature extraction
Drainage Maps	ALOSPALSAR	Automated water flow tracking
Slope Maps	ALOSPALSAR	Calculated gradient
Land Use/Land Cover	European Space Agency's Sentinel-2A Imagery	10 meters
Soil Type Maps	World Soil Type Maps (FAO)	Global coverage
Rainfall Data	Nigerian Meteorological Records	Nationwide network
Geological Data	Nigerian Geological Survey Agency	Variable

DEM data collecting requires topography-accurate sensors (Bangen et al. 2014; Gillan et al. 2017). This study LiDAR sensor records elevation data with 5 cm vertical and 1 m horizontal resolution. DEM data authenticity is essential for remote sensing and GIS map and analysis accuracy (Gillan et al. 2017; Kessar et al. 2021). DEM data is collected for remote sensing and GIS utilizing contemporary sensors and software algorithms to accurately assess topographic data. The custom program reduces noise and artefacts in raw LiDAR data to reconstruct ground surface elevation. Raster DEMs display landscape elevation as a grid from point clouds (George et al. 2022).

The lineament, drainage, and slope maps in this study were produced using the DEM data (Aladeboyee et al. 2021; George et al. 2022; Adewumi et al. 2023). By identifying linear features based on details like their length and orientation, automated feature extraction methods were used to extract the lineament and lineament density data from the DEM data. Using algorithms that track water flow throughout the landscape and determine the length and density of the stream network, the drainage and drainage density maps were created using the DEM data (Dinagarapandi et al. 2020; George et al. 2022). By figuring out the gradient of the landscape at each site, the slope maps were created using the DEM data. In this study, the lineament, drainage, and slope maps were created using the DEM data that was obtained by aerial LiDAR.

Maps of land use and land cover provide details on the location and extent of various land use and land cover types in a certain area. The European Space Agency's (ESA) Sentinel-2A imagery was used in this study to create the land use/land cover map. With a spatial resolution of 10 meters, Sentinel-2A is a satellite mission that provides high-resolution optical pictures of the Earth's surface (Adewumi et al. 2023). The satellite is equipped with a multispectral imaging sensor that can take pictures in 13 different spectral bands, from the visible to the infrared spectrum (Adewumi et al. 2023).

The physical and chemical characteristics of the soils in a specific location, such as their texture, pH, level of organic matter, and availability of nutrients, are described by soil type maps. The data for the soil type map in this study was taken from a map of soil types around the world (Adewumi et al. 2023). Global coverage of soil types is provided through world soil type maps created by international organizations like the Food and Agriculture Organization (FAO) of the United Nations, which combine field data, remote sensing, and modelling.

Rainfall is a significant environmental component that has an impact on the climate, hydrology, and many other parts of the Earth's system. Data on rainfall were gathered for this study from Nigerian meteorological records. The data on rainfall was gathered from a nationwide network of meteorological stations that track weather-related variables like precipitation, temperature, humidity, and wind speed (Adewumi et al. 2023). The regional and temporal variability of rainfall was evaluated using the rainfall data.

The distribution and properties of rocks, minerals, and geological structures in the research region are described by the geological data collected from the Nigerian Geological Survey Agency. The data includes geological maps, reports, and databases that contain information about the lithology, stratigraphy, and tectonic history of the area. The data also provides information about mineral resources and potential hazards such as landslides, earthquakes, and volcanic eruptions.

3.3. GIS/RS Data Preprocessing and Preparation of Thematic Layers for Groundwater Potential Assessment

Based on the data that was available at the research location, a number of thematic layers were developed to estimate groundwater potential zones. For this, seven effective parameters—geology, rainfall, slope, land use/cover, soil type, drainage, and lineament density—were chosen and used.

Groundwater occurrence was also found to be influenced by land use and cover (Roy et al. 2022). Different forms of land cover can either help retain water by reducing runoff or increase evapotranspiration, which can lower groundwater levels. The study region included several forms of land cover, such as vegetation, built-up areas, arid land, agricultural areas, and water bodies. The early creation of a summary of land use and land cover relied on visual interpretation. Then, utilizing the proper band combinations, supervised classification using the maximum likelihood classifier was carried out (George et al. 2022). The generated land-use map was then divided into categories to identify possible groundwater regions.

Groundwater presence, as well as the size and distribution of aquifers and aquitards in a certain location, are greatly influenced by the composition and properties of geological strata, including lithology, stratigraphy, and structure (Ibuot et al. 2022). Soil type has a direct impact on the aquifer rocks' porosity and permeability. The soil type map for the study area was digitally created from an Imo state geology map. Given the importance of soil type in determining groundwater potential, the map was further categorized to prepare for groundwater mapping.

RS data can show drainage patterns, which are crucial indicators of the groundwater potential. The drainage pattern, texture, and density of a region are significantly influenced by the underlying lithology (George et al. 2022). While moderate drainage density denotes intermediate groundwater potential, high drainage density indicates an area that is averse to the occurrence of groundwater. On the other hand, locations with little or no drainage density suggest ideal circumstances for groundwater presence. A drainage density map can be produced by the drainage pattern, which can be deduced from the DEM (Adewumi et al. 2023). The generated map can then be categorized to identify regions with potential for groundwater for future examination. The drainage density Dd per kilometre used in geospatially estimating the map in the study is given by equation 1:

$$Dd = \frac{L}{A} \tag{1}$$

where L is the total length of the channel in kilometres and A is the areal expanse of the study in square kilometres. Lineaments, which are made up of intersecting linear features, provide important information about the occurrence, flow, and storage of groundwater. They act as helpful checklists for locating prospective groundwater resources (Adewumi et al. 2023; Arshad et al., 2020). Lineament density maps were produced for this investigation using the spatial analyzer tool. To identify areas of varied lineament density, these maps were further categorized, providing essential data for determining groundwater potential.

3.4. Weighting of Thematic Maps using the Analytic Hierarchy Process (AHP)

AHP uses matrices to estimate the relative importance of factors for mathematical decision-making (Ejepu, 2020; Mogaji et al., 2021). Considering one aspect at a time simplifies decision-making and improves transparency and organization (Ifediegwu, 2022; Ghosh et al., 2022). AHP helps decision-makers prioritize goals by placing them at the top of a hierarchy. Its advantage over prior multi-attribute value systems is systematic assessment consistency (Ejepu et al., 2017; Ghosh et al., 2022; Thapa et al., 2022). Change priorities to establish consistency, which can fix inconsistent judgements. Reevaluation is usually needed when the consistency ratio (CR) exceeds 0.1.

The study's topics were assessed using a pairwise comparison matrix indicating groundwater occurrence, transportation, and storage criteria' relative preferences (Table 2). Two themes or classes were explored during weight normalization using

AHP (Wind and Saaty, 1980) and Saaty's scale to identify groundwater potential and recharge zones. Pairwise comparison matrices with specified weights were created for each thematic layer and class, and the eigenvector technique normalised them. The consistency ratio (CR) was used to evaluate the thematic layer and class normalised weights (Wind and Saaty, 1980). The CR computation allowed weight accuracy evaluation, guaranteeing a rigorous and open technique for groundwater potential and recharging zone location (Mogaji et al., 2021).

Square matrix: A = a_{ij} (equation 2), the element of row *i* column j was produced and the lower triangular matrix L_{ij} was completed by taking the reciprocal values of entries of the upper diagonal using the expression $\left(L_{ij} = \frac{1}{a_{ij}}\right)$.

$$A = \begin{bmatrix} \frac{p_1}{p_1} & \frac{p_1}{p_j} & \frac{p_1}{p_m} \\ \frac{p_i}{p_1} & 1 & \frac{p_i}{p_m} \\ \frac{p_n}{p_1} & \frac{p_n}{p_j} & \frac{p_n}{p_n} \end{bmatrix} \tag{2}$$

The given equation (2) defines a square matrix A with elements denoted as a_{ij}, where i and j represent the row and column indices, respectively. The elements of this matrix are obtained by dividing the value of p_i by the value of p_j, where p_i and p_j are entries from a given set of numbers p_1, p_2, ..., p_n.

The resulting matrix A will have the form of a lower triangular matrix, where all the elements above the diagonal are zero. This is because the matrix is constructed by dividing values of p_i by values of p_j, where i and j satisfy i ≤ j. Therefore, any element of A above the diagonal (i.e., a_{ij} where i > j) will be of the form p_j /p_i, which is not included in the matrix A.

We use the reciprocal values of the entries in the top diagonal to finish the lower triangular matrix A. We specifically substitute the reciprocal value, $1/a_{ij}$, for each element a_{ij} when i > j. Due to the fact that a_{ij}= p_i/p_i = 1, this results in a lower triangular matrix where all the diagonal entries are 1 and all the elements above the diagonal have been swapped out for their reciprocals. The resulting matrix A is a lower triangular matrix that has been finished by using the specified expression to find the reciprocal values of entries on the upper diagonal.

To get normalized relative weight, we divide each element of matrix $a_{ij} = \frac{p_i}{p_j}$ by equation 2 to obtain equation 3.

$$\frac{\frac{p_i}{p_j}}{\frac{\sum_{i=1}^{n} p_i}{p_i}} = \frac{p_i}{p_j} \times \frac{p_j}{\sum_{i=1}^{n} p_i} = \frac{p_i}{\sum_{i=1}^{n} p_i} \tag{3}$$

In equation (3), the fraction $(\frac{p_i}{p_j})$ in the numerator is manipulated by expressing it in terms of the sum of all the values in the set p_1, p_2, ..., p_n, which appears in the denominator. The first step is to divide both the numerator and denominator by p_j, then express $(\frac{p_i}{p_j})$ as the product of p_i and the reciprocal of p_j (Arefin 2020). The expression is simplified by multiplying both the numerator and denominator by p_j, resulting in the product of p_i and p_j, divided by the square of the sum of all the values in the set p_1, p_2, ..., p_n.

Averaging across the rows to get the normalized Principal Eigenvector (priority vector) i.e., Rate (R_i) or weight of row *i* (W_i) equation 4 resulted. Since it is normalized, the sum of all elements in the priority vector should be one.

$$\frac{W_i}{R_i} = \left[\frac{P_i}{\sum_{i=1}^{n} P_i} \dots \dots + \cdots \frac{P_i}{\sum_{i=1}^{n} P_1}\right] \times {}^{1}/_{n} \tag{4}$$

To compute λ_{max}, first multiply the normalized value by the respective weight and then, the values of the product are added together to get

$$\lambda_{max} = \frac{C_1 + C_2 + C_3 \dots C_n}{n} \tag{5}$$

where C_1 to C_n is the λ value and n is the number of criteria. In this research, a λ_{max} value of 5.1966 was obtained.

Eigenvalues are scalar values that are associated with a square matrix and are important in linear algebra and related subjects (Aykut 2021). Solving the characteristic equation, which includes determining the roots of a polynomial, yields the eigenvalues of a matrix.

The maximum eigenvalue, or λ_{max}, is the greatest of a matrix's eigenvalues. It may be used to calculate matrix attributes such as stability, convergence rate, and spectral radius. In some applications, obtaining the greatest eigenvalue is desired, and numerical methods can be employed to determine its value. A λ_{max}value of 5.1966 was achieved in this study, suggesting that the matrix under examination has the highest eigenvalue of 5.1966.

A measure of the consistency or degree of consistency of the judgment is called the consistency index, which is calculated using

$$C_i = \frac{(\lambda_{max} - n)}{n - 1} \tag{6}$$

where n is the number of criteria taken into account. AHP breaks down complex issues into a hierarchy of criteria, sub-criteria, and alternatives for decision-making (Albayrak and Erensal 2004; Gillan et al. 2017). Then, each pair of factors is compared for importance or preference. The AHP analysis calculates a $C_i$value by calculating the matrix of pairwise comparisons, which includes the decision maker's subjective opinions. After normalisation, the matrix's eigenvector shows the decision's criterion or alternatives' weights (Gillan et al. 2017).

This study produced a CI value of 0.04915, indicating a consistent pairwise comparison matrix. This number is often compared to a random index or C_i's anticipated value to determine consistency. If the $C_i$value is higher than predicted, the judgements may be wrong and require further investigation or matrix revision. Pairwise comparisons were examined using the Consistency Ratio (CR) within each thematic layer (Wind and Saaty, 1980). CR was calculated using Equation 7:

$$CR = \frac{C_i}{RCI} \tag{7}$$

C_i stands for consistency index.

The pairwise comparison matrix's consistency is measured by Saaty's RCI. This formula was established by Saaty (1987), and the outcomes depend on how many variables are compared. If the C_i value is greater than the RCI, the results may be wrong or the pairwise comparison matrix has to be changed or examined. A 5-variable pairwise comparison matrix for the study's RCI is 1.12. This value can be compared to the pairwise comparison matrix $C_i$value. CI values below 1.12 indicate matrix consistency. If the $C_i$value is more than 1.12, the pairwise comparison matrix is inconsistent and may need further investigation or change.

The computed CR achieved in this investigation is 0.04915, which is less than the threshold value of 0.10 (Mogaji et al., 2021; Wind and Saaty, 1980), indicating an acceptable level of inconsistency. If the CR is greater than 0.10, judgments should be reevaluated to ensure consistency in the decision-making process. After allocating rates for classes within each layer and weights for the thematic layers, a weighted overlay method was used to create the final map (Tamiru and Wagari, 2021; Girma, 2022). Equation 8 was applied to the spatial analysis tool in ArcGIS 10.8 to calculate the groundwater potential index (GWPI).

$$GWPI = \sum_{i=1}^{n} W_i \times R_i \tag{8}$$

where W_i is the weight for each thematic layer and R_i is rates for the classes within a thematic layer derived from AHP.

Table 2

Measurement scale of AHP (Wind and Saaty, 1980)

Scale	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one element over another

5	Strong importance	Experience and judgment strongly favour one element over another.
7	Very strong importance	One element is favoured very strongly over others. Its dominance is demonstrated in practice.
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
2,4,6,8	Intermediate value between the two adjacent judgments	It can be used to express intermediate values

The weights assigned to each thematic layer were determined using the Analytical Hierarchy Process (AHP) method. AHP is a decision-making technique that allows for the systematic comparison and ranking of alternatives based on multiple criteria.

The criteria were the different thematics (Rainfall, Geology, Slope, Drainage Density, LULC, Lineament Density, and Soil Type) and the alternatives were the different areas in the study region. The pairwise comparison matrix was filled out using a scale of 1 to 9, with 1 indicating equal importance and 9 indicating extreme importance. Comparing Rainfall and Geology, a value of 9 might indicate that Rainfall is much more important than Geology, while a value of 1 might indicate that they are equally important.

Table 3

Matrix of Environmental Factors and Normalized Principal Eigenvector Percentages for Groundwater Potential

Matrix		Rainfall	Geology	Slope	Drainage Density	LULC	Lineament Density	Soil Type	Normalized principal Eigenvector (%)
		1	2	3	4	5	6	7	
Rainfall	1	1	3	3	5	5	5	7	39.5
Geology	2	1/3	1	3	3	5	5	5	23.5
Slope	3	1/3	1/3	1	1	3	3	5	12.5
Drainage Density	4	1/5	1/3	1	1	1	2	3	8.0
LULC	5	1/5	1/5	1/3	1	1	1	3	6.1

Linea-ment Density	6	1/5	1/5	1/3	½	1	1	1	5.4
Soil Type	7	1/7	1/5	1/5	1/3	1/3	1	1	5.0

The AHP approach was used to calculate the weights for each theme after the pairwise comparison matrices for each thematic layer were finished. Based on the pairwise comparison matrix, the AHP technique applies a mathematical formula to determine the relative weights of the criterion. The proportionate weights given to each theme were based on how important they were in assessing the research area's overall suitability for a certain application. Rainfall (39.5%), Geology (23.5%), Slope (12.5%), Drainage Density (8.0%), LULC (6.1%), Lineament Density (5.4%), and Soil Type (5.0%) were given the following weights in this scenario as shown in Table 3. These weights represent how significant each theme is in assessing the study area's overall suitability for various applications, such as land-use planning or natural resource management. By assigning weights to each thematic based on their relative importance, the AHP method can provide a more objective and systematic approach to decision-making in GIS analysis.

4. RS AND GIS ANALYSIS

4.1. Lineament and Lineament Density

Lineaments are linear characteristics seen on the surface that act as markers for fissures and cracks connected to the presence of groundwater (Suganthi et al., 2013; Sahu et al., 2022). According to Mabee et al. (1994), Magowe and Carr (1999), and Solomon and Ghebreab (2006), these lineaments can be cracks, faults, fractures, and other geological formations that have linear properties or behave as groundwater flow channels. Given the importance of lineaments in the transport and storage of groundwater, the study imported lineament data into the ArcGIS environment and used the spatial analyst tool to produce a map of the density of lineaments in the studied area. A visual representation of the developed lineament density map is shown in Figure 3. The lineament density map measures the length of linear features per unit area and, by highlighting locations with higher lineament density—which often correlate to permeable layers or units—indirectly indicates groundwater potential. According to Solomon and Ghebreab (2006), lineament density polygons with higher density values indicate greater groundwater recharge and, therefore, improved groundwater prospects. The places with the highest lineament density are given the highest rating value to emphasize their importance for groundwater storage. Additionally, lineament crossings are prospective sites for groundwater storage, suggesting that regions with a lot of lineaments may have a lot of groundwater potential.

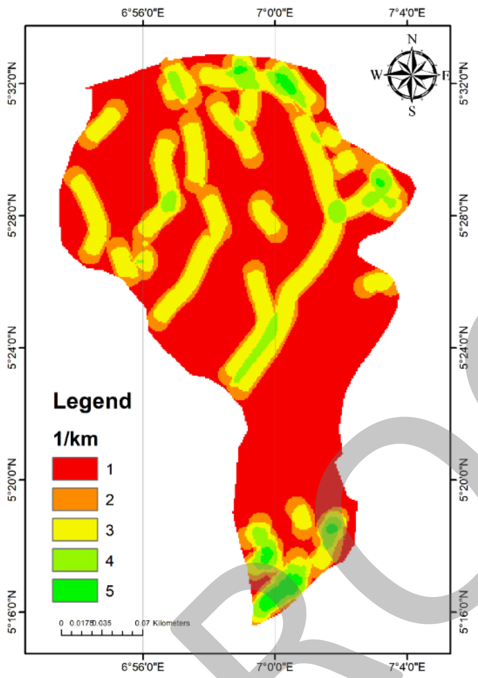

Figure 3
Reclassified lineament density of the study area

4.2. Land use/Land cover Map

The land use and cover of the research region affect the presence of groundwater. The results of the supervised classification of the land use and land cover maps are shown in Figure 4. The investigation showed that forests, built areas, and rangelands—three forms of land cover—dominate the research region. Groundwater is significantly impacted by land use and cover because it influences runoff by reducing or encouraging runoff and because it can also help plants retain water on their surfaces (Fan et al., 2022). The water droplets that are caught during this procedure eventually fall to the ground and help replenish the groundwater table. However, it is crucial to remember that, assuming a continual interception process occurs, land use and land cover can also negatively impact groundwater through evapotranspiration.

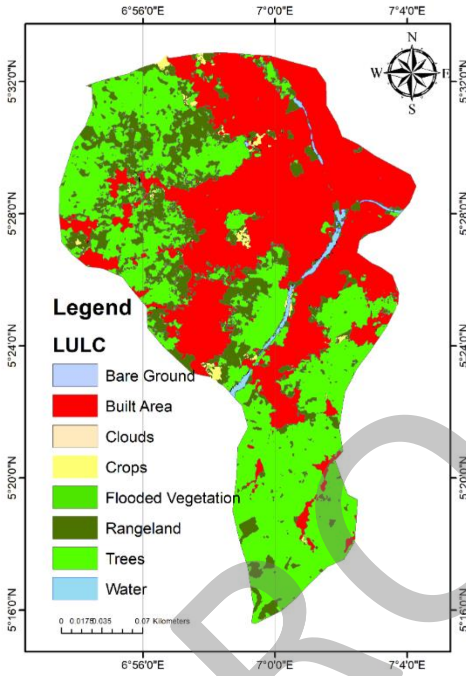

Figure 4

Land Use / Cover map of the study area

4.3. Drainage and Drainage Density Maps

Figure 5, which was directly derived from the DEM data, shows the drainage system of the study region. The type of vegetation, the soil's ability to absorb precipitation, infiltration, and the slope's gradient all have an impact on the drainage pattern. It performs as an essential hydrogeological characteristic indicator. The ratio of the total stream lengths to the region under consideration is represented by the surface drainage density, which is expressed in kilometres per square kilometre. Low drainage density areas encourage infiltration and lessen surface runoff, which is advantageous for the development of groundwater (Cotton, 1964; Luijendijk, 2022). According to Figure 5, the research region has a range of drainage densities between 1 and 5 km^{-1}, with a sizeable percentage being made up of low-density zones between 1 and 2 km^{-1}. This suggests that the study area has significant groundwater potential (Ekanem et al., 2022).

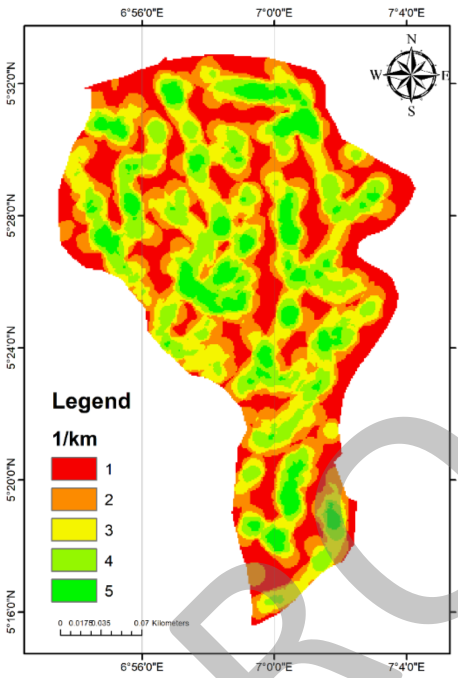

Figure 5
Drainage Density of the study area

4.4. Slope Maps

Groundwater infiltration and recharge are significantly influenced by the slope of the surface. It can shed light on the potential for groundwater in a particular area when used in conjunction with other geomorphic characteristics. Rainwater has more time to soak into the earth and replenish the groundwater system in low-slope locations since there is less surface runoff in these areas. High-slope locations, on the other hand, often have quick surface runoff, which reduces the amount of time that an area can be occupied by infiltration and recharging. In this study, DEM data and the spatial analyst tool in ArcGIS were used to create the slope map (Figure 6) of the research area. A slope of 1 degree is typically shown on the slope map in Figure 6, which indicates a strong potential for infiltration and recharge. This may indicate that the area has greater water potential (Magesh et al., 2012).

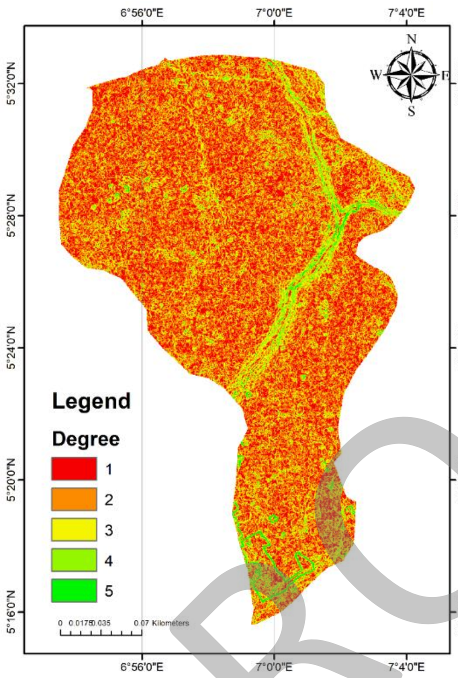

Figure 6

The slope of the study area

4.5. Soil Type Map

To develop the lithology layer for this investigation, the existing soil type map was digitalized. As illustrated in Figure 7, the examination of the remote sensing data revealed that sandy soils predominate in the region, with little sandy clay. According to Ekanem et al. (2022), this shows that the area is distinguished by porous and permeable soil, indicating a significant potential for groundwater.

Xantric Ferralsols are permeable, well-drained soils that are typical in tropical climates. They include a lot of iron and aluminium, which makes it simple for water to infiltrate and lessens surface runoff. Their moderate to high fertility and ability to serve as natural filters reduce the amount of toxins that seep into the groundwater. Dystric Nitosols, on the other hand, have low fertility and a high clay content. They frequently inhabit chilly regions with average to high rainfall. Their low permeability prevents groundwater recharging by encouraging surface runoff and preventing water infiltration. Because of the poor natural fertility, there may be a tendency to use more fertilizer, which, if used improperly, might contaminate groundwater (Adewumi et al. 2023).

However, the low permeability and low fertility of dystric nitosols may prevent groundwater recharge and increase the usage of fertilizers, both of which increase the danger of groundwater contamination. These soil features should be taken into account for managing groundwater supplies and maintaining water quality (George et al. 2022).

Another important factor to consider is the type of soil in the area. Soils with high water-holding capacity, such as clay-rich soils, can retain water for longer periods, allowing it to percolate down into the ground and recharge the aquifers. Sandier soils, on the other hand, may not be able to hold onto as much water, resulting in a lesser potential for groundwater. Groundwater potential is significantly influenced by rainfall. The potential for groundwater in a region is greatly influenced by factors such as soil type, rainfall intensity, volume, and distribution.

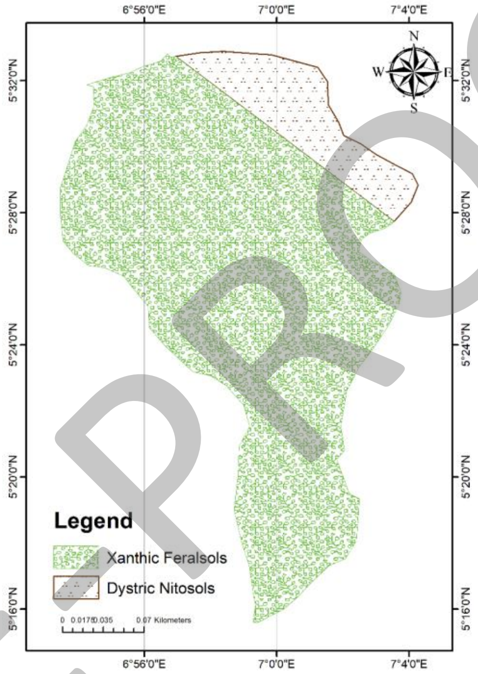

Figure 7

Soil Type of the study area

4.6. Rainfall

Rainfall data is critical in geomorphology studies because it helps identify places with varied levels of groundwater potential. Figure 8 shows the various rainfall within the study area. Groundwater potential is higher in areas with high yearly rainfall because there is more water available to filter into the ground and recharge aquifers. Regions with little annual rainfall, on the other hand, have reduced groundwater potential since there is less water available for recharge.

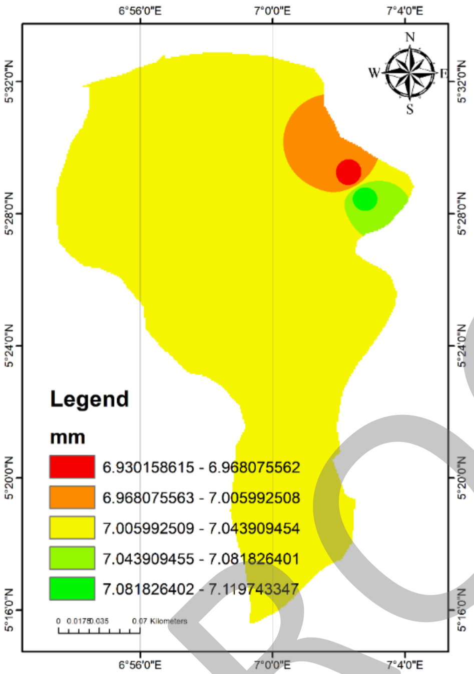

Figure 8
Rainfall of the study area

However, it is important to note that rainfall timing and distribution are also important factors in affecting groundwater potential. If a location receives a large amount of rainfall in a short period of time, the water may not have enough time to soak into the earth and effectively recharge the aquifers. Similarly, irregular rainfall distribution throughout the year may not be enough to keep groundwater levels stable during dry months. As a result, rainfall data is a core sort of geomorphology data utilized in hydrological studies, which are critical in assessing a region's water resources (Adewumi et al. 2023).

4.7. Geology

Aquifer units, particularly sandstone layers, are present in the Benin Formation (Figure 9) and play a crucial role in the storage and transport of groundwater (George et al. 2022). The sandstones have increased porosity and permeability, which allows water to pass through and makes it easier to extract groundwater. Rainfall infiltration is the primary mechanism by which groundwater is recharged, and regions with sufficient precipitation and infiltration conditions have a high potential for recharging. The thickness, extent, porosity, and saturation levels of the sandstone aquifers within the Benin Formation can affect how much groundwater they can hold. To ensure groundwater quality within the formation, potential sources of contamination, such as agriculture, industry, and natural mineral deposits, should be taken into account.

Groundwater quality varies depending on local geology and hydrogeological conditions (George et al. 2022).

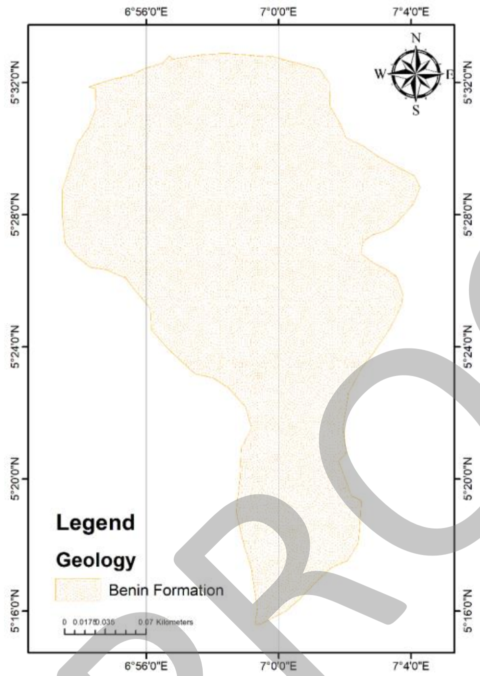

Figure 9

Geology of the study area

4.8. Groundwater Potential Map

The groundwater potential index map, as shown in Figure 10, is the result of the combination of numerous thematic maps. The groundwater potential index (GPI) map for the research area was created by allocating weights and combining the thematic maps pertaining to groundwater occurrence, transit, storage, and recharge. Three distinct zones—poor, fair, good, and excellent—are shown on the map. After thorough consideration, it becomes clear that the lineament density, slope, land use, and soil type are the main determinants of the groundwater potential in the research region. Particularly, there is enormous groundwater potential in the southern areas of the region, which are distinguished by a high lineament density and various slope conditions. The study's overall finding is that the area's groundwater potential index ranges from poor to excellent. These results are consistent with those of Ikpe et al. (2022) and Ejepu et al., (2022) studies.

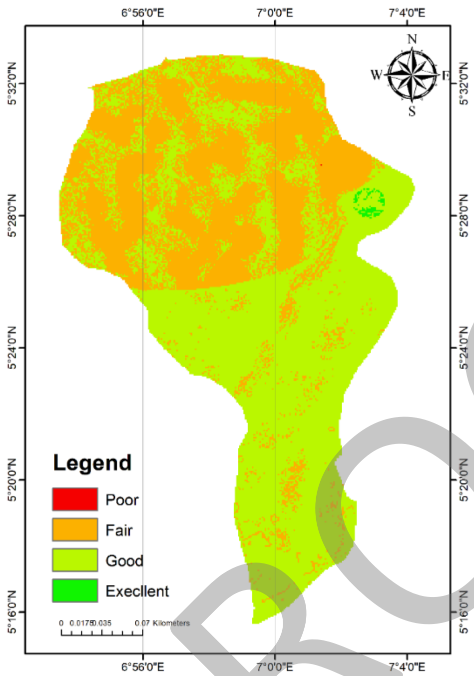

Figure 10
Groundwater Potential area of the study area

According to the analysis, the most important elements affecting groundwater potential were rainfall (39.5%), geology (23.5%), slope (12.5%), drainage density (8.0%), land use/land cover (6.1%), lineament density (5.4%), and soil type (5.0%). A high degree of consistency in the conclusions reached was shown by the computed consistency ratio (CR) for this study, which was found to be 0.04915, much below the criterion of 0.10. Rainfall, geology, soil type, lineament density, slope, drainage density, and land use or cover affected groundwater potential in the study region. The AHP method made ranking these components by importance in determining groundwater potential easier. Combining the maps produced a complete groundwater potential map of the research region. The study found modest groundwater potential with patches of excellent potential within its limitations. Southern portions of the research area had fair to good groundwater potential.

This study reveals how important multiple elements are when measuring groundwater potential. For successful water resource management and planning, geology, rainfall, slope, drainage density, lineament density, and land use and cover must be considered to identify high groundwater potential. The study found that modest slopes and lineament densities from 1 to 5 km^{-1} were common in the area. The study found considerable regional variations in the study area's groundwater potential, which were highly connected with other factors. High rainfall, good geology, low to average slopes, high drainage density, high lineament density, and optimal land use and cover have been shown to have great groundwater potential. Zones with low to moderate slopes and high lineament density have the most groundwater potential.

5. CONCLUSION

The analysis conducted for this study provides crucial insights into the potential for groundwater in the studied area. Lineament density, an indicator of permeable units, is important for groundwater potential estimation. Higher lineament densities improved groundwater outlooks and recharge potential. Groundwater storage was also considered at line intersections. This information can influence future groundwater investigations. According to the land use and land cover map, the research region had many trees, population areas, and rangeland. Vegetation aids the groundwater cycle by reducing runoff and encouraging infiltration. Land cover's water-holding capacity helps recharge groundwater. Careful management of land use and land cover on groundwater potential reduces contamination risk.

The drainage and drainage density maps illustrate that the drainage system is important for hydrogeological evaluation. Groundwater growth was best in low drainage density areas because they increased infiltration and reduced surface runoff. The analysis showed that the studied region had several low drainage densities, indicating a large groundwater potential. Groundwater infiltration and recharging were controlled by slope in the studied region. Low slope readings suggested enhanced infiltration and groundwater residence time, increasing groundwater potential.

The soil type map showed the research area's aquifer rocks' porosity and permeability. Permeable and filtering xantric ferralsols were found to recharge groundwater and filter pollution. However, dystric nitosols' low permeability and fertility made groundwater recharge difficult and polluting. Groundwater potential depended heavily on rainfall data. High annual rainfall locations have higher groundwater potential because more water is available for infiltration and aquifer recharge. The timing and distribution of rainfall must be considered to ensure efficient recharge and groundwater stability year-round.

An index map of groundwater potential was created when all theme maps were integrated. Zones of low, moderate, and extraordinary groundwater potential were delineated in the research area. The correctness of the groundwater potential map was guaranteed by the regular and precise weighing of components according to relevance. This work emphasises a comprehensive approach that combines remote sensing, GIS analysis, and the AHP. Groundwater potential and occurrence can be comprehended with the use of advanced instruments and a variety of variables. Planning, groundwater sustainability, and the management of water resources are all dependent on this knowledge in the research region.

By considering variables including lineament density, land use and cover, drainage density, slope, soil type, geology, and rainfall, a full understanding of groundwater occurrence, storage, and recharge patterns has been gained. In order to ensure that the groundwater resources of the area are utilized sustainably, the findings might serve as a starting point for upcoming groundwater exploration, management, and planning projects.

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