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GIS-Based Hybrid Approach for Groundwater Potential Mapping and Analysis in Owerri Municipal, Imo State Nigeria

Ossai, E.N[1]., Igbokwe, E.C[2], and Okoli, G.C[2]

Student, Nigeria

ABSTRACT-

Groundwater is an essential resource for domestic, agricultural, and industrial uses, particularly in urban areas where surface water is unreliable or insufficient. In Owerri Municipal, Imo State, Nigeria, increasing urbanization and the absence of a centralized water supply system have led to an overreliance on groundwater abstraction through boreholes and wells, hence the study aimed at a GIS-based hybrid approach for groundwater potential mapping and analysis in Owerri Imo State. The objectives are to: identify and select the key conditioning factors influencing groundwater potential in the study area; assess and rank the relative importance of the conditioning factors using the Entropy Weighting Method and the Analytical Hierarchy Process (AHP); classify the ranked conditioning factors based on their levels of groundwater potential; delineate groundwater potential zones through a weighted overlay analysis and generate a groundwater potential map indicating varying levels of groundwater availability across the study area. Seven key groundwater conditioning factors—slope, land use/land cover (LULC), geology, soil, drainage density, lineament density, and rainfall—were identified, standardized, and converted into thematic layers. The study employed both the Entropy Weighting Method and the Analytical Hierarchy Process (AHP) to assign objective and expert-based weights to each factor. A hybrid weighting approach was developed by averaging the two weight sets, enhancing the reliability of the analysis. The final groundwater potential map was generated using the weighted overlay tool in ArcGIS Pro 3.2, and classified into five categories: Very Low, Low, Moderate, High, and Very High potential. The results indicated that the Moderate Potential Zone was most dominant, covering 2,812.65 hectares (48.84%) of the study area. This was followed by Low Potential (41.08%), High Potential (8.75%), Very High Potential (1.31%), and Very Low Potential (0.03%). These findings provide crucial insights for effective groundwater resource planning and sustainable management. Given the application of the GIS-based hybrid modeling approach in delineating groundwater potential zones in Owerri Municipal, it is recommended that this methodology be expanded to other local government areas and potentially applied across Imo State to support integrated water resource management planning.

Keywords: Analytical Hierarchy Process, Entropy, Groundwater, Imo State, Owerri Municipal

1. Introduction

Groundwater is one of the most vital natural resources supporting global water demand for domestic, agricultural, industrial, and ecological purposes. It accounts for approximately one-third of the world's freshwater withdrawals and serves as the primary source of potable water for over 2.5 billion people, especially in regions where surface water is scarce or contaminated (Foster & Chilton, 2003; MacDonald et al., 2012). In developing countries such as Nigeria, groundwater plays a pivotal role in sustaining urban and rural populations due to its relative reliability, accessibility, and resilience to climatic variability (Adelana et al., 2008).

Despite its importance, groundwater resources are under increasing stress from population growth, urbanization, land use change, and over-extraction, leading to declining water tables, contamination, and aquifer depletion (Oni et al., 2019; Ahmed et al., 2021). The challenge is further complicated by the lack of accurate, spatially distributed information on subsurface water availability, which hampers planning and sustainable management. In this context, modern geospatial technologies such as Geographic Information Systems (GIS), remote sensing (RS), and machine learning-based modeling offer promising solutions for assessing and mapping groundwater potential zones (Jha et al., 2007; Chowdhury et al., 2010).

GIS provides a robust platform for integrating multi-thematic spatial data including geology, geomorphology, land use/land cover (LULC), drainage density, slope, rainfall, soil type, and elevation—factors known to influence groundwater occurrence (Magesh et al., 2012). Remote sensing data, especially from satellite platforms such as SRTM, Landsat, and Sentinel, enhance spatial resolution and temporal consistency, improving the accuracy of groundwater potential zone delineation (Kumar et al., 2014). However, single-method approaches often fail to capture the inherent complexity of groundwater systems. Therefore, hybrid models that integrate multiple decision-making frameworks—such as Analytical Hierarchy Process (AHP), Frequency Ratio (FR), and Machine Learning (ML) techniques—have emerged as more reliable alternatives (Rahmati et al., 2016; Naghibi et al., 2017).

Owerri Municipal, the capital city of Imo State, Nigeria, is experiencing rapid urbanization, land transformation, and increasing water demand. The area is characterized by moderate relief, sandy-loam soil, and a tropical rainforest climate—all of which significantly influence groundwater recharge and storage. The over-reliance on boreholes and hand-dug wells in the face of increasing population pressure has intensified the need for a reliable groundwater potential map to guide sustainable water resource planning (Ehirim & Ebeniro, 2010; Oke et al., 2020). Unfortunately, groundwater exploitation in the area is often unguided, with drilling locations chosen arbitrarily or based on anecdotal evidence.

A GIS-based hybrid modeling approach offers a scientific, spatially explicit, and cost-effective method for assessing groundwater potential in Owerri Municipal. By incorporating multiple physical and anthropogenic factors and employing weighted decision-making models such as AHP in combination with data-driven techniques like frequency ratio or logistic regression, it becomes possible to identify suitable zones for groundwater development with higher precision and confidence (Saaty, 1980; Das, 2019). This study, therefore, seeks to develop a groundwater potential map for Owerri Municipal using a GIS-based hybrid model, integrating remote sensing datasets and multi-criteria evaluation to inform planning, reduce drilling failures, and ensure sustainable groundwater management.

2. Materials and Methods

2.1 Study Area Description

Owerri is the capital of Imo State in Nigeria (see fig 1.1). Owerri consists of three Local Government Areas namely: Owerri Municipal, Owerri North and Owerri West (see fig 1.2 & 1.3). Owerri is bordered by the Otamiri River to the east and the Nworie River to the south. It is located between latitudes 5° 20’N and 5° 30’N and longitudes 6° 55’E and 7° 5’N.

2.2 Data Requirement

In this study, a variety of spatial and attribute data were acquired and processed to derive the thematic layers essential for modeling groundwater potential. The selection of datasets was based on their hydrological significance, spatial resolution, and compatibility with GIS-based analytical procedures. The major data inputs used in this research include:

a) ALOS PALSAR Digital Elevation Model (DEM)

The Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) DEM was used to derive topographic parameters such as slope and drainage density. With a spatial resolution of 12.5 meters, the ALOS PALSAR DEM provides high-resolution elevation data that accurately represent surface variations. These parameters play a crucial role in determining surface runoff characteristics, water accumulation zones, and the infiltration potential of the terrain. The dataset was obtained from the Japan Aerospace Exploration Agency (JAXA) data archive.

b) Soil Data

Soil characteristics such as texture, porosity, and permeability directly influence groundwater recharge and movement. Infiltration rates vary significantly across soil types, making soil data a key input in groundwater potential modeling. The soil data used in this study were sourced from the FAO Harmonized World Soil Database and complemented by national soil survey maps. These were digitized, classified, and restructured into thematic layers suitable for raster overlay analysis.

c) Rainfall Data

Rainfall represents the primary source of groundwater recharge, particularly in tropical environments such as South-East Nigeria. Spatially distributed rainfall data were required to assess variations in recharge potential across the study area. Meteorological data were obtained from the Nigerian Meteorological Agency (NiMet), covering annual average rainfall for the past decade. The data were spatially interpolated using the Inverse Distance Weighting (IDW) method to generate a continuous rainfall surface raster.

d) Geology Data

The geological framework of an area dictates the nature of aquifers and their capacity to store and transmit groundwater. Different lithologies exhibit varying porosities and permeability levels. For this study, a digitized geological map of the study area was obtained from the Nigerian Geological Survey Agency (NGSA). The geology layer was prepared by classifying the major rock units based on their aquifer properties and potential for groundwater accumulation.

e) Landsat 8 Operational Land Imager (OLI)

Landsat 8 OLI imagery was used for land use/land cover (LULC) classification, which is essential for understanding the surface characteristics influencing infiltration. Built-up areas, agricultural lands, vegetation, and water bodies all exhibit distinct recharge behaviors. The Landsat 8 data, with a spatial resolution of 30 meters, were acquired from the United States Geological Survey (USGS) Earth Explorer platform. Supervised classification was conducted in ERDAS Imagine and validated using field-based ground control points and Google Earth imagery.

2.3 Identification and Preparation of Groundwater Conditioning Factors

The identification and preparation of relevant groundwater conditioning factors constitute a critical phase in the modeling of groundwater potential zones. These factors influence the processes of infiltration, storage, movement, and recharge of groundwater, and their selection must be informed by hydrogeological theory, previous empirical studies, and the physical characteristics of the study area. In this study, seven thematic layers were identified as key determinants of groundwater potential in Owerri Municipal. These include slope, land use/land cover (LULC), geology, soil, drainage density, lineament density, and rainfall. Each layer was prepared using remote sensing data, field records, and existing cartographic datasets, and was processed using a consistent spatial framework within a Geographic Information System (GIS) environment.

2.3.1 Slope

Slope is one of the most influential topographic parameters affecting groundwater recharge. It determines the rate at which surface runoff occurs and influences the potential for infiltration. Gentle slopes facilitate water percolation into the soil, enhancing recharge, while steep slopes promote rapid runoff and decrease the opportunity for infiltration. In this study, slope was derived from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with a 30-meter spatial resolution. Using the spatial analyst tools in ArcGIS, the elevation data were processed to produce a slope raster in degrees. This slope raster was then classified into five categories reflecting groundwater recharge potential, ranging from very low to very high.

2.3.2 Land Use / Land Cover (LULC)

Land use and land cover significantly impact the surface’s permeability and consequently its ability to allow water infiltration. Different land cover types exhibit varying hydrological behaviors. For instance, vegetation and farmlands facilitate infiltration, while urban and built-up areas hinder it due to impervious surfaces. In this study, LULC data were derived from Landsat 8 Operational Land Imager (OLI) satellite imagery. The imagery was classified using supervised classification techniques within ERDAS Imagine software, with field verification points and Google Earth imagery used for validation. The classified LULC map was then rasterized and reclassified into groundwater potential classes based on land cover type, with water bodies and forests rated highest, and built-up areas rated lowest.

2.3.3 Geology

The geological composition of an area governs the subsurface properties such as porosity, permeability, and aquifer structure. Geological formations such as sedimentary basins are more likely to store and transmit groundwater compared to crystalline rocks unless fractured. In this study, the geology of Owerri Municipal was obtained from geological maps provided by the Nigerian Geological Survey Agency (NGSA). The maps were digitized and georeferenced in ArcGIS to produce a geological raster layer. Each lithologic unit was assigned a groundwater potential value based on its ability to store and transmit water. Although the final reclassification of this layer was handled separately due to its complexity, the geology layer remains fundamental in delineating the hydrostratigraphy of the area.

2..3.4 Soil

Soil type affects both infiltration capacity and water retention, and thus plays a key role in groundwater recharge dynamics. Sandy and loamy soils, for instance, promote rapid infiltration, while clayey soils impede it due to their fine texture and low permeability. Soil data for the study area were sourced from FAO soil maps and other relevant national soil datasets. These were digitized, georeferenced, and converted into raster format in ArcGIS. Each soil class was assigned a groundwater suitability score based on its permeability and water retention characteristics. Like the geology layer, soil reclassification was handled separately, but its preparation and integration were essential for the overall groundwater potential model.

2.3.5 Drainage Density

Drainage density, defined as the total length of streams per unit area, serves as a key indicator of surface runoff and infiltration. Areas with low drainage density tend to exhibit higher infiltration and are therefore more favorable for groundwater recharge. Conversely, high drainage density suggests efficient runoff and limited infiltration capacity. The drainage density map was derived from the SRTM DEM using the Hydrology toolset in ArcGIS. Flow direction and flow accumulation rasters were generated to extract stream networks, which were then vectorized and analyzed using the Line Density tool to produce a drainage density raster. This raster was categorized into five classes to reflect its impact on recharge potential.

2.3.6. Lineament Density

Lineaments, which include faults, joints, and fractures visible on the earth’s surface, often serve as conduits for groundwater movement in fractured rock aquifers. The density and orientation of these features influence the secondary porosity and permeability of the underlying geology. In this study, lineaments were identified using directional filters and edge-enhancement techniques applied to satellite imagery in ArcGIS. These features were manually digitized into vector format and then converted into a lineament density raster using the Line Density tool. Areas with higher lineament densities were considered to have higher groundwater potential due to enhanced connectivity and subsurface flow pathways.

2.3.7 Rainfall

Rainfall provides the primary input for natural groundwater recharge. Its spatial variability influences the amount of water available for percolation, especially in the absence of surface runoff barriers. Average annual rainfall data were collected from nearby meteorological stations for a multi-year period. The point data were spatially interpolated using the Inverse Distance Weighting (IDW) method in ArcGIS to generate a continuous rainfall surface. This raster layer was then categorized into five potential zones, with higher rainfall zones assigned higher recharge potential classes.

All thematic layers were standardized to the same spatial resolution (30 m), aligned to a common coordinate reference system (WGS 1984 UTM Zone 32N), and clipped to the boundary of Owerri Municipal to ensure consistency. The resulting layers formed the basis for reclassification, weighting, and integration in the subsequent groundwater potential modeling workflow.

2.4 Reclassification and Standardization of Thematic Layers

In order to ensure that the selected thematic layers could be objectively compared and integrated in a multi-criteria overlay analysis, each layer was reclassified and standardized to a common scale. This process involved converting raw raster data values—each measured in different units and ranges—into a unified ordinal classification scheme. The standardized scale adopted in this study ranged from **1 to 5**, where:

1 represents Very Low groundwater potential,

2 denotes Low potential,

3 indicates Moderate potential,

4 represents High potential, and

5 corresponds to Very High groundwater potential.

This classification approach aligns with widely adopted practices in groundwater potential modeling and was guided by hydrological literature, expert consultations, and data-driven thresholds.

The reclassification procedure was applied to the five conditioning factors processed directly within this study: slope, land use/land cover (LULC), drainage density, lineament density, and rainfall. The other two factors—soil and geology—were prepared and reclassified separately due to the categorical nature of their datasets and were incorporated during the weighted overlay phase.

Each raster layer was reclassified using logical breakpoints that reflect the influence of the factor on groundwater occurrence. For example, slope values were grouped into intervals reflecting hydrological conditions—gentle slopes were assigned higher potential values due to their infiltration-enhancing effects, while steep slopes were assigned lower values due to higher runoff. Similarly, drainage density was reclassified such that areas with low stream concentration (i.e., low drainage density) were assigned higher scores, reflecting their greater likelihood of allowing water infiltration. In contrast, high drainage density zones were considered less favorable and received lower scores due to increased surface runoff and reduced recharge opportunity.

The land use/land cover (LULC) layer was reclassified based on the permeability and infiltration characteristics of different land use types. For instance, water bodies and forested areas were rated highest, while urban/built-up zones were rated lowest. Lineament density was classified such that areas with high fracture and fault concentration were rated high due to their potential for enhanced groundwater storage and transmission. Rainfall was divided into zones based on interpolated annual precipitation values, with higher rainfall regions assigned greater recharge potential.

Reclassification was implemented using the Reclassify tool in ArcGIS Pro 3.2, where each raster was grouped into five ordinal classes based on defined breakpoints. The outputs were then verified for consistency and alignment. The resulting standardized rasters were projected to the same coordinate system (WGS 1984 UTM Zone 32N) and resampled to a uniform 30-meter resolution to ensure spatial congruence during overlay modeling.

This reclassification step ensured that all layers could contribute comparably to the final weighted overlay, despite their diverse origins and data ranges. It also allowed each conditioning factor to be interpreted on a consistent groundwater potential scale, thereby facilitating transparent and logical combination in subsequent spatial modeling operations.

2.5 Weight Determination

To accurately evaluate the relative contribution of each conditioning factor to groundwater occurrence, it is essential to assign appropriate weights that reflect their influence on groundwater recharge, storage, and movement. In this study, a hybrid weighting strategy was adopted by integrating both Entropy Weighting Method (EWM)—an objective, data-driven approach—and the Analytical Hierarchy Process (AHP)—a subjective, expert-driven method. This dual approach ensured that both the inherent variability within the data and expert hydrogeological insights were captured in the final modeling process.

2.5.1 Entropy Weighting Method (EWM)

The Entropy Weighting Method is a statistical technique used to measure the degree of disorder or variability in a dataset. It is based on the assumption that a factor with higher variation contributes more information and should therefore be given a higher weight. The entropy method relies on the information theory principle that uniform distributions provide less useful information than skewed distributions.

The steps involved in entropy weighting were as follows:

1. Each reclassified raster dataset was normalized by dividing each pixel value by the total sum of all pixel values in the layer. This produced a normalized decision matrix where the sum of pixel values for each layer equaled one.
2. The entropy value ($\boldsymbol{ej}$) for each conditioning factor was calculated using the formula:

$$e_j = -k \sum_{i=1}^{m} p_{ij} \cdot \ln(p_{ij}), \quad \text{where } k = \frac{1}{\ln m}$$

Here, pij represents the normalized value of the ith pixel in the jth factor, and m is the total number of observations (pixels).

3. The degree of diversification for each factor was derived as:

$$dj = 1 - ej$$

This value indicates the discriminative power of each factor. Higher values imply higher spatial variability and therefore more influence on the final output.

4. The final entropy-based weight for each factor was computed as:

$$wj = \frac{d_j}{\sum d_j}$$

The entire entropy weighting process was automated using Python scripting in Jupyter Notebook, employing libraries such as NumPy and Pandas for data manipulation and raster processing.

2.5.2 Analytical Hierarchy Process (AHP)

The AHP method involves structuring the decision-making process into a hierarchical model and assigning weights based on expert pairwise comparisons. This technique allows for the inclusion of human judgment in assessing the relative importance of various factors based on their physical, hydrological, and environmental relevance.

The procedure for AHP weight determination included the following steps:

1. A 7 × 7 matrix was constructed, where each element represents the comparative importance of one factor over another using Saaty's fundamental scale (ranging from 1 to 9).
2. The comparison matrix was normalized by dividing each element in a column by the total of that column, thereby converting raw scores into relative values.
3. The priority weight for each factor was derived by averaging the normalized values across each row.
4. To ensure that the pairwise comparisons were not arbitrary, a consistency index (CI) and consistency ratio (CR) were calculated using the formulas:

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \quad CR = \frac{CI}{RI}$$

Where λmax is the maximum eigenvalue of the matrix, n is the number of factors, and RI is the random index. A CR less than 0.1 (10%) was considered acceptable. The CR obtained in this study was 0.028, indicating a high level of internal consistency.

The AHP analysis was performed in Microsoft Excel 2019, which facilitated matrix normalization, eigenvalue computation, and consistency validation.

2.5.3 Hybrid Weighting Scheme

To enhance the reliability and objectivity of the final model, the Entropy and AHP weights were combined using the arithmetic mean method. This hybrid approach compensates for the weaknesses of relying solely on either statistical variation (Entropy) or expert judgment (AHP).

The final hybrid weight for each factor was computed using the formula:

$$W_{\text{Hybrid}} = \frac{W_{\text{Entropy}} + W_{\text{AHP}}}{2}$$

This process produced a balanced weighting scheme that integrates both spatial heterogeneity and expert-derived priorities, forming the basis for the weighted overlay analysis conducted in the next stage of the study.

2.6 Weighted Overlay Analysis

The weighted overlay analysis is a core step in the spatial modeling of groundwater potential zones. It involved the integration of all standardized thematic layers, each multiplied by its respective weight, to compute a composite index—known as the Groundwater Potential Index (GWPI). The GWPI reflects the cumulative influence of the selected conditioning factors and is used to classify the study area into zones of varying groundwater potential.

In this study, the weighted overlay analysis was implemented using the Weighted Overlay tool in ArcGIS Pro 3.2. This tool allows for the combination of multiple raster layers by applying specific weights to each input and summing the results to produce a final raster that represents the overall suitability or potential.

2.6.1 Input Preparation

Each of the seven thematic layers—slope, land use/land cover, geology, soil, drainage density, lineament density, and rainfall—was first reclassified to a common ordinal scale ranging from 1 (Very Low Potential) to 5 (Very High Potential). These reclassified rasters were stored in a geodatabase and aligned spatially by projecting them to the same coordinate reference system (WGS 1984 UTM Zone 32N) and resampling them to a consistent resolution of 30 meters.

2.6.2 Application of Hybrid Weights

The hybrid weights derived from the integration of Entropy and AHP methods were assigned to the respective thematic layers. Each raster layer was multiplied by its corresponding hybrid weight, reflecting the relative contribution of that factor to groundwater recharge and accumulation.

For example, lineament density, which received the highest weight due to its strong influence on subsurface water movement, exerted a greater impact on the final overlay result compared to lower-weighted factors such as slope or soil. The weighted raster layers were then summed cell by cell to produce a cumulative groundwater potential surface using the equation:

$$GWPI = \sum_{i=1}^{n} (F_i \times W_i)$$

Where:

Fi = Reclassified raster value of factor i

Wi = Hybrid weight assigned to factor i

n = Total number of conditioning factors (in this case, 7)

This operation resulted in a continuous raster surface with varying pixel values corresponding to groundwater potential scores across the study area.

2.6.3 Classification of Groundwater Potential Zones

The GWPI raster was classified into five groundwater potential zones using the Natural Breaks (Jenks Optimization) classification method. This method was selected because it minimizes within-class variance while maximizing between-class variance, producing well-defined and statistically meaningful categories. The classified groundwater potential zones include:

1. Very Low Potential
2. Low Potential
3. Moderate Potential
4. High Potential
5. Very High Potential

The final groundwater potential map was validated visually and statistically to ensure logical spatial continuity and consistency with known hydrogeological patterns. Map outputs were exported for presentation and interpretation, and the area coverage of each class was calculated using the Zonal Statistics tool in ArcGIS. This overlay operation completed the spatial modeling framework, producing a decision-support output that enables the identification of priority zones for groundwater exploration and sustainable water resource planning within Owerri Municipal.

2.7 Area Estimation and Zonation Mapping

Following the weighted overlay analysis and classification of the Groundwater Potential Index (GWPI) raster, the next step involved quantifying the spatial extent of each groundwater potential class across the study area. This was necessary to determine the relative proportion of land within each category—Very Low, Low, Moderate, High, and Very High potential zones—and to inform groundwater development and resource allocation strategies.

2.7.1 Area Estimation

To calculate the area coverage of each groundwater potential zone, the classified GWPI raster was processed using the Zonal Histogram and Zonal Statistics tools in ArcGIS Pro 3.2. Each pixel in the raster, representing a 30-meter by 30-meter grid cell, was assigned to one of the five groundwater potential classes based on the natural breaks' classification of the GWPI values. The total number of pixels in each class was then multiplied by the pixel area (0.0009 km^2) to derive the total area (in square kilometers) covered by each potential zone. This computation enabled a detailed understanding of how groundwater suitability is distributed across the landscape of Owerri Municipal. The results showed that the Moderate Potential Zone occupied the largest land area, indicating that nearly half of the municipality possesses reasonably favorable hydrogeological characteristics for groundwater recharge. The Low Potential Zone followed closely, while the High and Very High Potential Zones were relatively limited in spatial extent but critical for groundwater exploitation. The Very Low Potential Zone was found to be negligible in area, indicating that unfavorable conditions are rare within the study region.

2.7.2 Zonation Mapping

The final output of the modeling process was a groundwater potential zonation map, visually depicting the spatial distribution of the five potential classes across the study area. This map was symbolized using a graded color scheme, ranging from red (Very Low Potential) to green (Very High Potential), for clear visual interpretation. Map elements such as north arrow, legend, scale bar, and coordinate grid were added to facilitate communication and usability.

The zonation map serves as a spatial decision-support tool, enabling stakeholders—including water resource managers, urban planners, and local government authorities—to identify and prioritize areas for groundwater development, artificial recharge interventions, and aquifer protection.

3. Results

3.1 Identification and Preparation of Thematic Layers of Groundwater Conditioning Factors

In fulfillment of the first objective, this study identified and prepared seven key thematic layers that are critical for evaluating groundwater potential within Owerri, Imo State. These layers—slope, land use/land cover (LULC), geology, soil, drainage density, lineament density, and rainfall—were selected based on their theoretical relevance, geohydrological significance, and consistent usage in similar geospatial groundwater studies across tropical environments. Each of these factors influences groundwater occurrence either by controlling the movement and storage of water in the subsurface or by affecting recharge dynamics.

The preparation of these thematic layers involved the use of Remote Sensing (RS) data, Geographic Information System (GIS) tools, and spatial modeling techniques. All datasets were converted into raster format at a consistent spatial resolution, projected to a common coordinate reference system (WGS 1984 UTM Zone 32N), and clipped to the administrative boundary of Owerri. This ensured seamless integration and comparability across all spatial layers during the weighted overlay process.

The slope layer (Figure 1) was derived from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with a spatial resolution of 30 meters. Using the slope analysis tool in ArcGIS, the elevation data was transformed into slope degrees, which were then reclassified into categories based on their steepness. The slope factor is vital in groundwater studies because it directly affects the rate of surface runoff and the likelihood of infiltration. Gentle slopes allow rainwater to percolate into the ground, thereby enhancing recharge, whereas steep slopes promote quick surface runoff, which reduces infiltration and groundwater accumulation.

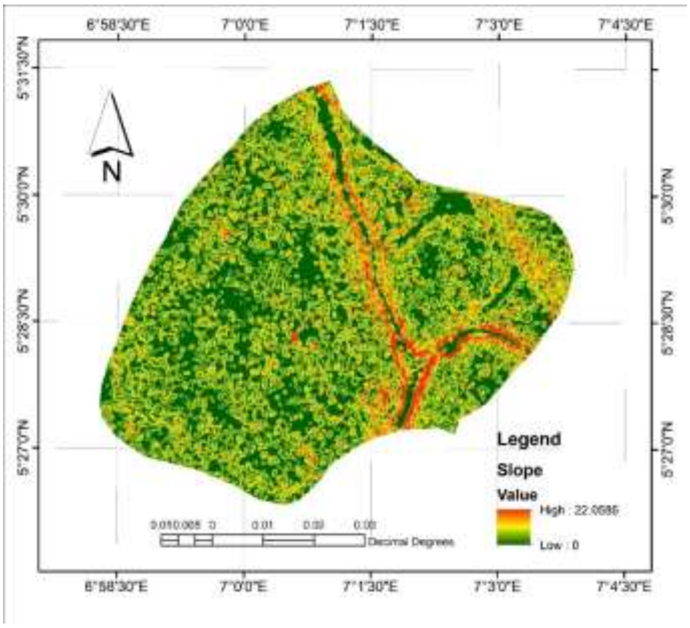

Figure 1: Slope Data

LULC (Figure 2) was extracted from recent multispectral satellite imagery (e.g., Landsat 8 OLI or Sentinel-2) using supervised classification methods in the remote sensing software environment. Ground truthing points and high-resolution Google Earth imagery were used to enhance classification accuracy. LULC influences the permeability of the land surface and the ability of rainfall to infiltrate the subsurface. Vegetated areas and farmlands promote infiltration, while built-up and impervious surfaces such as roads and buildings hinder echarge. Therefore, LULC is a key determinant in assessing the spatial variation of groundwater recharge zones.

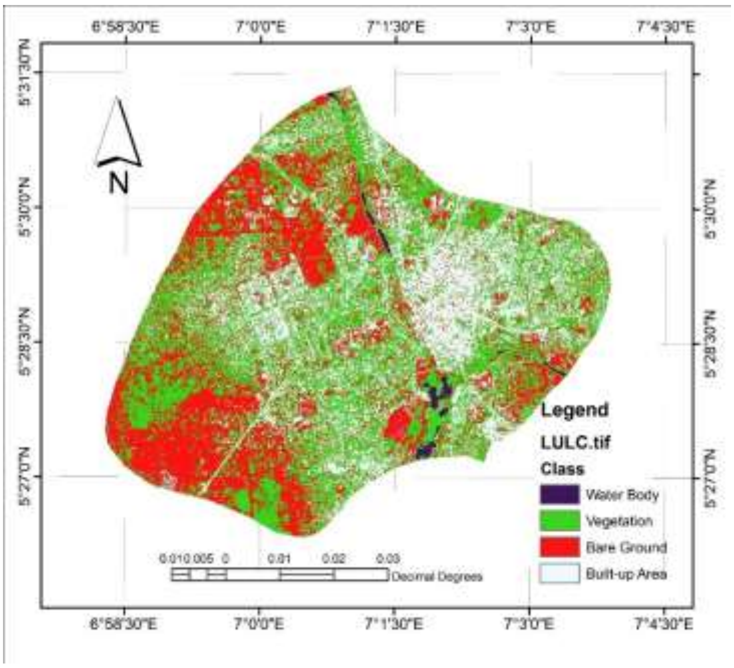

Figure 2: Landcover/Landuse Data

Geological data (Figure 3) for the study area was obtained from existing geological maps provided by the Nigerian Geological Survey Agency (NGSA). The maps were digitized and converted into raster format. The geology layer indicates the type of bedrock and structural features present in the area, which significantly influence groundwater storage and movement. Porous sedimentary formations are typically associated with higher aquifer potential, whereas crystalline or impermeable rocks limit subsurface water movement unless fractured. The presence of fault zones or fractured rock can also create preferential pathways for groundwater accumulation.

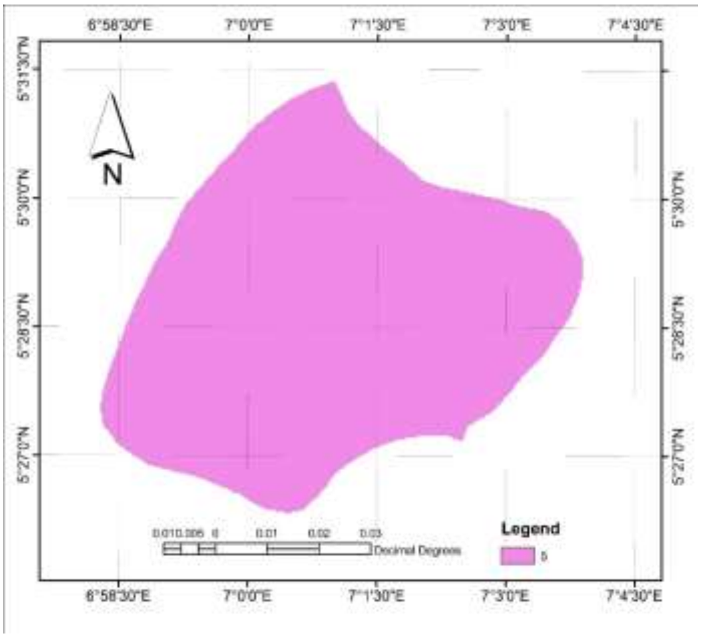

Figure 3: Geology Data

Soil data (Figure 4) was sourced from digital soil survey maps published by relevant environmental or agricultural agencies. The vector-based soil maps were georeferenced, digitized, and rasterized in a GIS environment. Soil texture, structure, and permeability are critical parameters that determine the infiltration rate of water into the ground and the soil's capacity to retain moisture. For instance, sandy and loamy soils favor infiltration and deep percolation, while clayey soils impede vertical movement of water, potentially reducing recharge rates.

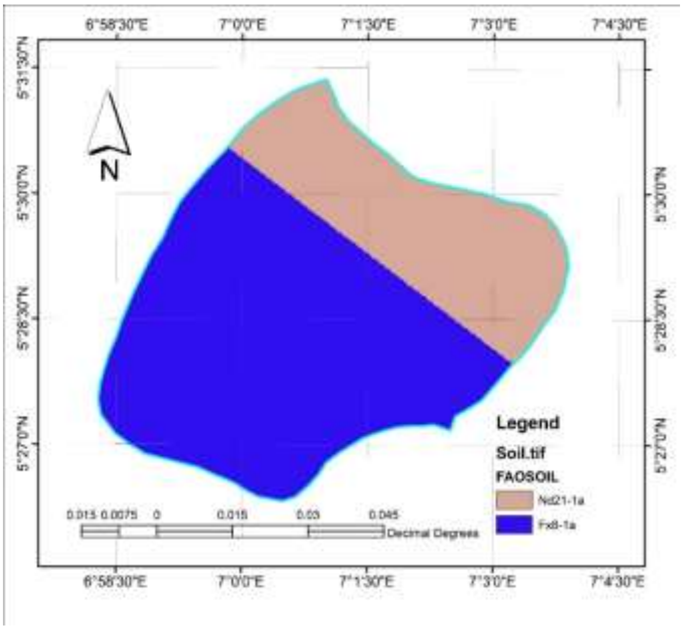

Figure 4: Soil Data

Drainage density (Figure 5) was computed from the hydrologically corrected SRTM DEM using flow direction and flow accumulation algorithms. The stream network was extracted using threshold values in ArcGIS Hydrology tools. Drainage density was then calculated as the total length of streams per unit area using the line density function. This factor reflects the efficiency of surface runoff removal. Areas with low drainage density are often associated with higher infiltration potential and thus better groundwater recharge capacity, whereas high drainage density zones tend to have limited groundwater potential due to increased surface runoff.

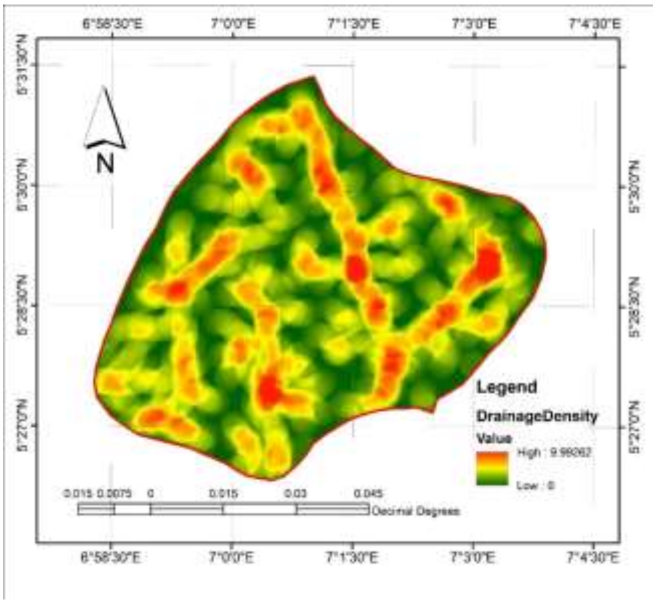

Figure 4.5: Drainage Density Data

Lineaments, (Figure 6) which include geological faults, fractures, and joints, were identified through remote sensing techniques, including edge enhancement and directional filtering applied to satellite imagery. The extracted lineaments were converted to vector format, and lineament density was calculated as the total length of lineaments per unit area using the line density tool. High lineament density suggests the presence of structural discontinuities that may enhance groundwater recharge and facilitate groundwater movement by creating secondary porosity in otherwise impermeable rocks. Thus, lineament density is one of the most important indicators of subsurface water-bearing structures in hard rock terrains.

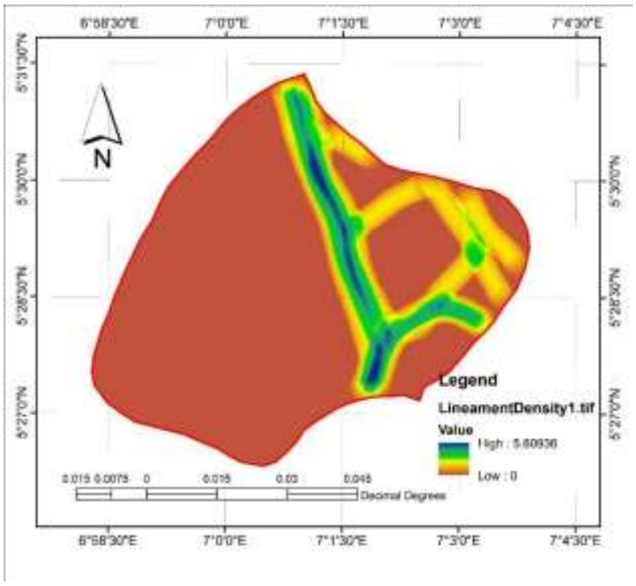

Figure 6: Lineament Density Data

Rainfall data (figure 4.7) was obtained from meteorological stations distributed across the region. The point data was interpolated into a continuous surface using the Inverse Distance Weighting (IDW) interpolation method in GIS. Rainfall is the principal source of natural groundwater recharge, and its spatial distribution directly affects the volume of water that can infiltrate the soil and reach the aquifer. Areas with higher average annual rainfall tend to have greater recharge potential, assuming that the underlying geological and soil conditions are favorable.

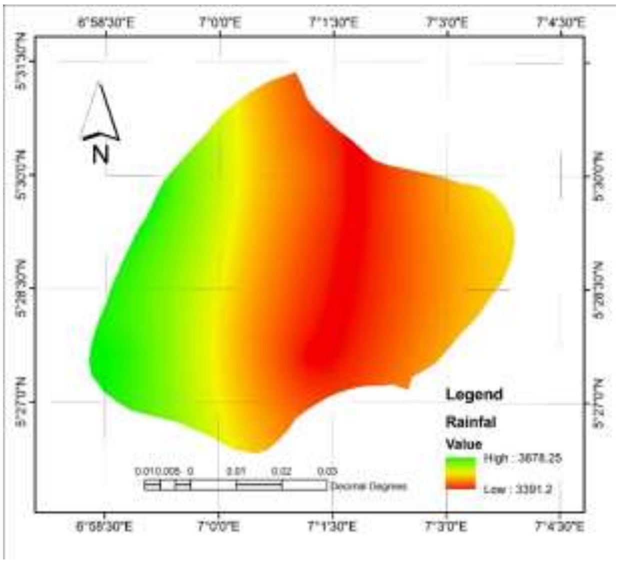

Figure 7: Rainfall Data

A summary of the thematic layers, their data sources, derivation techniques, and justification for inclusion is presented in Table 1.

Table 1: Summary of Groundwater Conditioning Factors and Justification for Inclusion

S/N	Thematic Layer	Source/Derivation Method	Relevance to Groundwater Potential Assessment
1	Slope	Derived from SRTM DEM using GIS tools	Controls surface runoff and infiltration; flatter areas favor groundwater recharge.
2	Land Use / Land Cover	Classified from Landsat/Sentinel imagery	Determines surface permeability; vegetation and open lands facilitate infiltration.
3	Geology	Digitized from NGSA geological maps	Determines aquifer types, rock porosity, and permeability characteristics.
4	Soil	Derived from soil survey datasets	Influences infiltration, water retention, and vertical percolation.
5	Drainage Density	Generated from DEM using flow algorithms	Low density implies more infiltration and less surface runoff.
6	Lineament Density	Extracted from remote sensing imagery	Indicates fractures and faults that act as conduits for groundwater flow and recharge.
7	Rainfall	Interpolated from meteorological station data	Primary input for groundwater recharge; spatial distribution affects recharge intensity and potential.

3.2 Reclassification and Standardization of Groundwater Conditioning Factors

In order to facilitate the integration of multiple thematic layers for the purpose of groundwater potential mapping, it is essential that each conditioning factor be standardized to a common interpretative scale. This standardization process ensures that the influence of each factor on groundwater occurrence is assessed uniformly across the study area. In this study, five conditioning factors—slope, land use/land cover (LULC), drainage density, lineament density, soil, geology and rainfall—were reclassified into a common suitability scale ranging from 1 to 5, where:

1 represents Very Low Groundwater Potential,

2 represents Low Potential,

3 represents to Moderate Potential,

4 represents High Potential, and

5 represents Very High Groundwater Potential.

This classification system is grounded in both empirical hydrological theory and established practices in groundwater modeling, with each class representing a relative contribution of the factor toward groundwater recharge, storage, or transmissivity. Each raster layer was processed using remote sensing and GIS tools to extract numerical values from satellite and geospatial datasets. These values were then systematically categorized into the five potential classes using defined threshold intervals that reflect the physical or environmental significance of the factor. The following paragraphs explain in detail the reclassification logic and the hydrological relevance of each factor to groundwater potential.

Slope plays a pivotal role in controlling the movement of surface water and its potential to infiltrate into the subsurface. Areas with gentle slopes tend to have slower surface runoff, which enhances infiltration and facilitates groundwater recharge. In contrast, steeply sloping terrain promotes rapid runoff, reducing the amount of water that percolates into the soil. For this reason, the slope raster, derived from the SRTM Digital Elevation Model (DEM), was reclassified using hydrologically meaningful intervals. Areas with slopes between 0 and 2 degrees were assigned a Very High potential (Class 5), as such regions provide ideal conditions for water infiltration. Slopes between 2 and 6 degrees were designated as High potential (Class 4), and 6 to 12 degrees as Moderate potential (Class 3). Areas with slopes ranging from 12 to 22 degrees were classified as Low potential (Class 2), and those exceeding 20 degrees were assigned to Very Low potential (Class 1). The reclassified slope layer showed a predominance of pixels in the Very High and High classes, indicating favorable topographic conditions for groundwater recharge across much of Owerri, see figure 8.

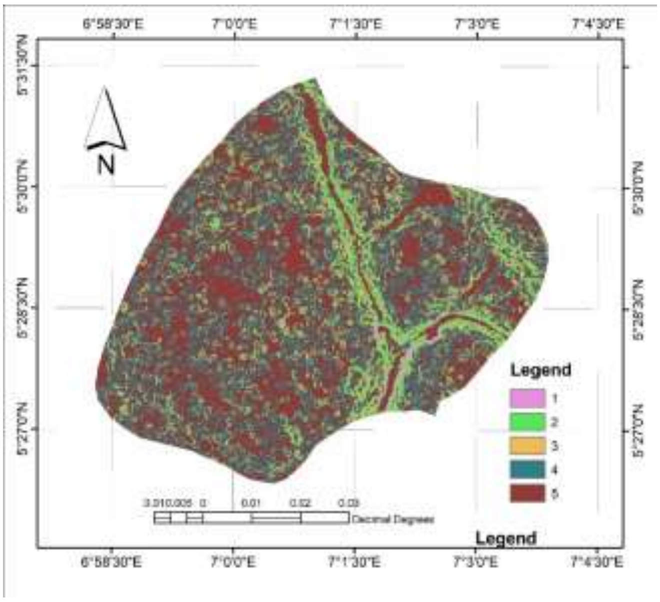

Figure 8: Reclassified Slope Data

Land use and land cover significantly influence the surface's capacity to absorb or repel water. Impervious surfaces such as buildings and paved roads hinder infiltration, leading to increased runoff, while vegetated and pervious surfaces such as forests, wetlands, and agricultural land enhance the percolation of rainwater. LULC was classified from multispectral satellite imagery using supervised classification, and each class was assigned a groundwater potential rating based on its hydrological properties. Water bodies were classified as Very High potential (Class 5) because they are direct sources of recharge and may represent zones of high-water table. Forested areas were categorized as High potential (Class 4) due to their high infiltration capacity and protective canopy. Agricultural land, with intermediate permeability, was placed under Moderate potential (Class 3). Barren land was considered to offer Low potential (Class 2) because of limited vegetative cover, and built-up areas were rated as Very Low potential (Class 1) due to their impervious nature. The distribution of reclassified LULC values showed that waterbodies were the dominant contributors to Very High potential zones in the raster, while urban areas were largely associated with low or very low potential, see figure 9.

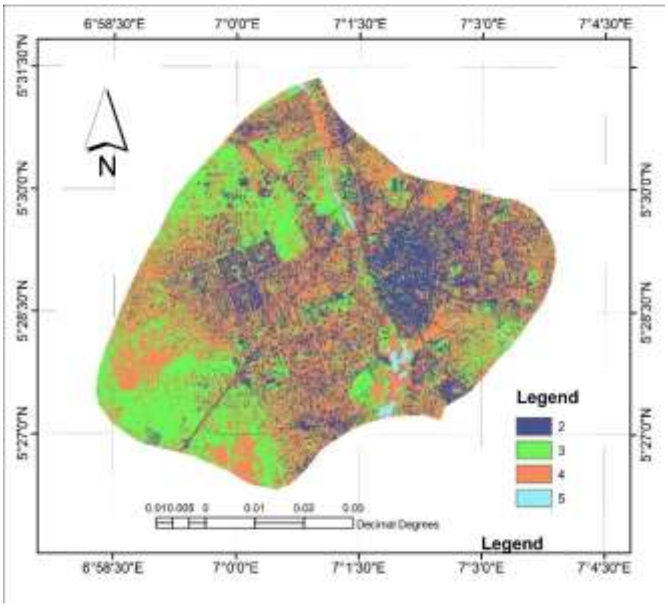

Figure 9: Reclassified LULC Data

Drainage density is defined as the total length of streams and rivers per unit area and serves as an important proxy for surface runoff behavior. High drainage density implies a highly dissected landscape with efficient runoff removal, which limits water infiltration and results in lower groundwater recharge. Conversely, areas with low drainage density are indicative of more compact basins where water has a greater opportunity to infiltrate. The drainage density raster, derived from flow accumulation algorithms applied to a DEM, was reclassified accordingly. Areas with values less than 1 km/km^2 were considered Very High potential (Class 5) because of their enhanced recharge conditions. Densities between 1–2 km/km^2 and 2–3 km/km^2 were classified as High (Class 4) and Moderate potential (Class 3), respectively. Drainage densities between 3–4 km/km^2 were rated as Low potential (Class 2), and values exceeding 4 km/km^2 were assigned Very Low potential (Class 1). The reclassification revealed that a considerable portion of the study area falls within the moderate to high groundwater potential categories, see figure 10.

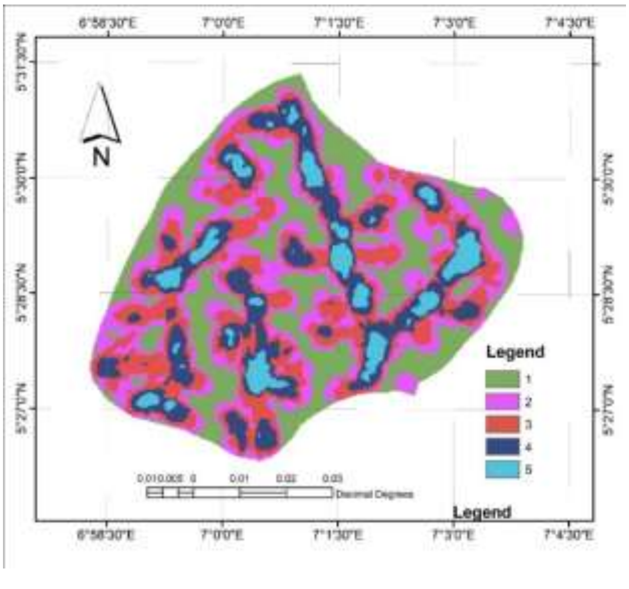

Figure 10: Reclassified Drainage Density Data

Lineaments represent zones of structural weakness in the bedrock, such as fractures and faults, which often act as conduits for groundwater movement. Areas with higher lineament density typically indicate increased secondary porosity and permeability, allowing for more efficient water storage and transmission. The lineament density raster was produced by digitizing structural features from remote sensing imagery and computing line density in GIS. It was reclassified so that regions with lineament density greater than 4 km/km^2 were assigned Very High potential (Class 5), while those between 3–4 km/km^2, 2–3 km/km^2, and 1–2 km/km^2 were categorized as High (Class 4), Moderate (Class 3), and Low (Class 2), respectively. Areas with lineament density less than 1 km/km^2 were rated as Very Low potential (Class 1). This reclassification affirmed the critical role of geological structure in groundwater potential mapping, particularly in areas underlain by crystalline basement rocks.

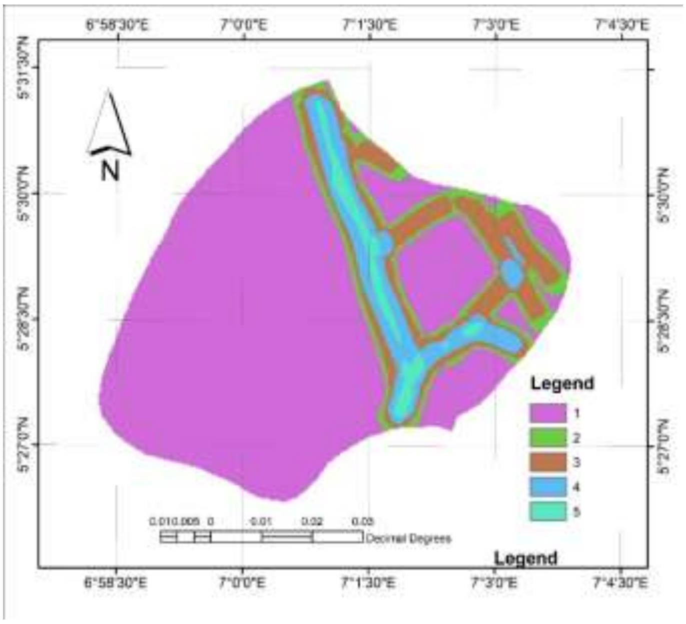

Figure 11: Reclassified Lineament Density Data

Rainfall is the primary source of natural groundwater recharge, and its spatial variability directly influences groundwater availability. Higher rainfall generally results in increased recharge volumes, particularly in regions with favorable infiltration conditions. The rainfall raster, generated through spatial interpolation (Inverse Distance Weighting) of point-based meteorological records, was reclassified based on annual average precipitation. Areas receiving 3631.89 - 3742 mm/year were classified as Very High potential (Class 5). Those with 3521.78–3631.89 mm/year and 3427.41–3521.78 mm/year were labeled High (Class 4) and Moderate (Class 3), respectively. Zones with rainfall ranging from 3353.25– 3427.41 mm/year were designated as Low potential (Class 2), while areas receiving less than 3169 – 3353.25 mm/year were assigned Very Low potential (Class 1). The reclassification showed that while a substantial area experienced moderate rainfall, the highest groundwater potential zones were more limited in areal extent, see figure 12.

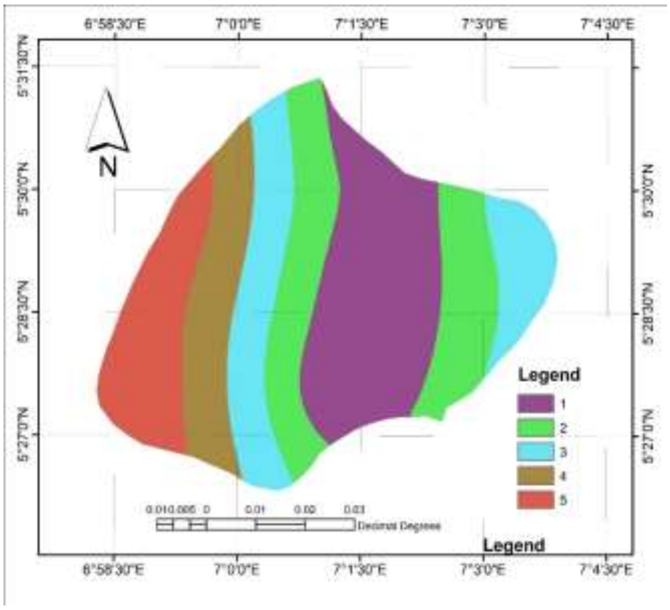

Figure 12: Reclassified Rainfall Data

The available soil and geological data for Owerri Municipal were of relatively low spatial resolution, necessitating further detailed investigation. Nonetheless, preliminary soil classification identifies the area as being predominantly covered by lithosols and red ferralsols. These soil types are generally well-drained and moderately permeable, characteristics that are favorable for groundwater infiltration. Based on these properties, the soils were reclassified as having very high groundwater potential, see figure 13.

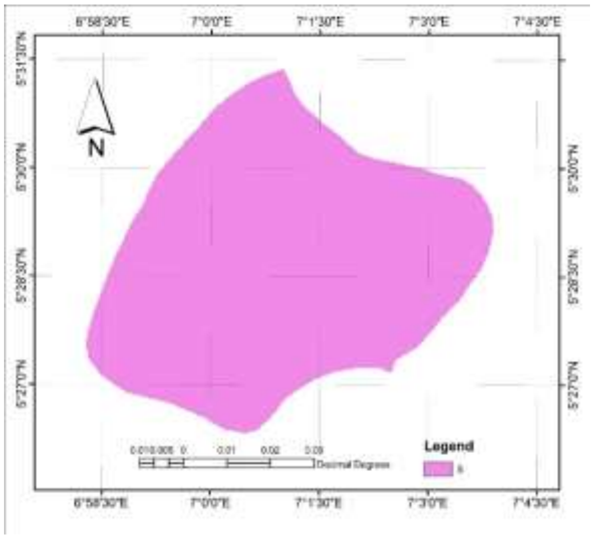

Figure 13: Reclassified Soil Data

Geological data indicated that the area is underlain by claystone, shale, and sandstone formations. Among these, sandstone is typically porous and permeable, contributing significantly to groundwater recharge and storage. While claystone and shale are generally less permeable, their presence in alternating sequences with sandstone still support aquifer development through confined or semi-confined conditions. Consequently, the geological formations were also reclassified as category (5): very high groundwater potential, based on their capacity to support groundwater accumulation and movement, see figure 14.

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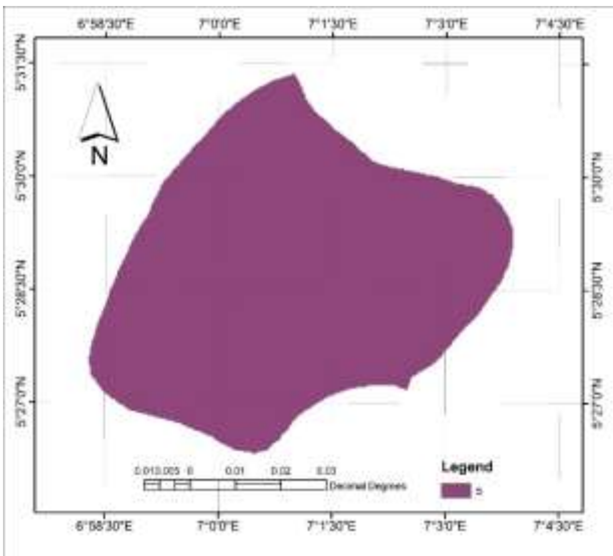

Figure 14: Reclassified Geology Data

3.3 Weight Derivation for Groundwater Conditioning Factors

In groundwater potential mapping using GIS-based multi-criteria analysis, the reliability of the final model is significantly influenced by the assignment of appropriate weights to each of the contributing factors. Weight derivation is the process of determining the relative importance of various thematic layers that affect the availability and accumulation of groundwater. In this study, seven key conditioning factors were considered based on their theoretical relevance and observed influence on groundwater occurrence in similar geologic and climatic settings. These factors include slope, land use/land cover (LULC), geology, soil, drainage density, lineament density, and rainfall.

Each of these layers was generated in raster format using geospatial data sources such as satellite imagery, digital elevation models (DEMs), and thematic maps. However, due to the spatially variable influence of these factors, it became necessary to quantify their relative significance in an objective and structured manner. This study adopted two well-established approaches for weight determination: the Entropy Weighting Method, which is an objective and data-driven technique, and the Analytical Hierarchy Process (AHP), which is a subjective method based on expert judgment. To enhance the robustness and accuracy of the final groundwater potential model, both weighting techniques were integrated using a hybrid averaging approach.

The following subsections describe in detail the application of each method, beginning with the Entropy Weighting Method, which focused on the statistical dispersion and informational contribution of each factor across the spatial extent of the study area.

3.3.1 Entropy Weighting Method

The Entropy Weighting Method is a quantitative and objective approach rooted in information theory, and it is particularly useful in multi-criteria decision-making (MCDM) scenarios where the spatial variability of data plays a crucial role. The fundamental idea behind the entropy method is that the greater the variation (or dispersion) in the values of a criterion, the more information it provides, and hence the more influence it should carry in the final decision-making process. In contrast, factors with uniform values across the study area contribute little useful information for distinguishing between zones of varying groundwater potential.

To implement this method, each of the seven conditioning factors was first prepared in raster format using GIS tools, and pixel values were extracted for analysis. These raw raster values were organized into a decision matrix, where each row represents a spatial unit (pixel) and each column corresponds to a thematic layer. In order to ensure comparability across the different factors, the data were normalized by dividing each pixel value by the sum of all pixel values for that factor, producing a proportional value for each spatial unit.

The output of this analysis is presented in Table 2, which shows the entropy values, diversification scores, and resulting weights for all seven groundwater conditioning factors.

Table 2: Entropy Weighting Results

Factor	**Entropy (ej)**	**Diversification (dj)**	**Weight (wj)**
Lineament Density	0.9112	0.0888	0.4538
Drainage Density	0.9546	0.0454	0.2322
Slope	0.9550	0.0450	0.2301
LULC	0.9861	0.0139	0.0713
Rainfall	0.9976	0.0024	0.0125
Geology	1.0000	0.00003	0.0002
Soil	1.0000	0.000000025	0.00000013

The results indicated that Lineament Density, Drainage Density, and Slope provided the highest information gain and thus carried the highest weights, while Soil and Geology exhibited negligible variability across the study area.

As indicated in the table, lineament density emerged as the most informative factor with the highest weight (approximately 45.4%), followed by drainage density (23.2%) and slope (23.0%). These three layers exhibited significant variability across the study area, indicating their strong influence on groundwater potential. Conversely, soil and geology had minimal or nearly uniform values, resulting in near-zero weights. This indicates that, within the context of Owerri, these factors may not significantly vary or influence groundwater recharge compared to others.

This objective weighting formed the first component of the hybrid model and provided a strong data-driven foundation for mapping groundwater potential in the study area.

3.3.2 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP), developed by Thomas Saaty in the 1980s, is a structured and widely used multi-criteria decision-making (MCDM) method that allows for the systematic evaluation of multiple factors based on expert judgment and pairwise comparisons. In groundwater potential mapping, AHP has proven particularly useful for assigning relative importance to factors whose influence cannot be easily quantified solely through statistical means. The method facilitates the transformation of qualitative assessments into a consistent quantitative scale.

In this study, the AHP was employed to complement the Entropy Weighting Method by integrating domain expertise into the weight derivation process. The seven selected conditioning factors—slope, land use/land cover (LULC), geology, soil, drainage density, lineament density, and rainfall—were evaluated through a pairwise comparison matrix. The comparison was made using Saaty's fundamental scale, which ranges from 1 (equal importance) to 9 (extremely more important), with reciprocal values assigned to inverse comparisons.

The pairwise comparison matrix was constructed by comparing the relative importance of each factor to every other factor in terms of its influence on groundwater potential. For instance, lineament density was considered to be significantly more influential than soil, and thus it was assigned a higher comparative value. The full pairwise comparison matrix is presented in **Table 3**, where each cell aij indicates the importance of factor i relative to factor j.

Table 3: Pairwise Comparison Matrix

	Slope	LULC	Geology	Soil	Drainage Density	Lineament Density	Rainfall
Slope	1	3	5	5	3	0.5	3
LULC	1/3	1	3	3	2	0.25	2
Geology	1/5	1/3	1	2	1/3	1/7	1
Soil	1/5	1/3	1/2	1	1/3	1/9	1
Drainage Density	1/3	1/2	3	3	1	1/5	2
Lineament Density	2	4	7	9	5	1	5
Rainfall	1/3	1/2	1	1	1/2	1/5	1

Once the matrix was completed, the sum of each column was computed to normalize the values. Each entry in the matrix was then divided by its corresponding column sum to produce the normalized pairwise comparison matrix, allowing for the computation of priority weights. These priority weights represent the average of the normalized values across each row, indicating the relative importance of each factor.

To ensure the consistency of the judgments made in the pairwise comparisons, a consistency check was performed. This involved calculating the weighted sum vector by multiplying the original pairwise matrix by the priority weights, followed by computing the consistency vector, which is the element-wise division of the weighted sum vector by the corresponding priority weight. The average of the consistency vector yields λmax $t$he maximum eigenvalue of the matrix. The Consistency Index (CI) and Consistency Ratio (CR) were then computed, yielding λmax $\boldsymbol{as}$ 7.220, CI as 0.0367 and CR as 0.028

Since the Consistency Ratio (CR) was less than 0.1, the judgments used in the pairwise comparisons were deemed acceptably consistent, and the resulting weights were considered reliable for use in groundwater potential modeling.

The final priority weights derived from the AHP process are shown in Table 4. Lineament density again emerged as the most important factor with a weight of 39.2%, consistent with the findings from the entropy analysis. This was followed by slope (23.5%) and land use/land cover (12.2%). On the lower end, soil and geology were assigned smaller weights, further corroborating their limited influence in the context of the study area.

Table 4: AHP Priority Weights and Consistency Ratio

Factor	AHP Weight
Lineament Density	0.3922
Slope	0.2349
LULC	0.1218
Drainage Density	0.0996
Rainfall	0.0584
Geology	0.0522
Soil	0.0409

The AHP method thus provided a structured means to incorporate expert knowledge into the modeling framework, ensuring that the spatial analysis was not solely dependent on data variability but also grounded in theoretical understanding and field-based observations.

3.3.3 Hybrid Weighting and Final Ranking

Given the individual strengths and limitations of both the Entropy Weighting Method and the Analytical Hierarchy Process (AHP), a hybrid weighting approach was adopted in this study to integrate the advantages of both methodologies and achieve a more balanced and robust evaluation of the groundwater conditioning factors. While the Entropy Method provides an objective, data-driven assessment of factor importance based on spatial variability and information content, AHP introduces expert knowledge and qualitative judgments that capture real-world understanding of the groundwater system. The hybrid approach, therefore, ensures that both statistical rigor and domain expertise are reflected in the final groundwater potential model.

To develop the hybrid weights, the normalized weights obtained from both the Entropy and AHP analyses were first rescaled to ensure that their individual sums equaled one. This normalization process allowed for a direct comparison and combination of the two independent weight sets. Following normalization, the hybrid weight for each factor was computed as the arithmetic mean of the corresponding Entropy and AHP weights. This simple averaging method was chosen for its ease of implementation and its ability to equally incorporate both objective and subjective perspectives.

The resulting hybrid weights were then used to rank the seven groundwater conditioning factors according to their integrated influence on groundwater occurrence and accumulation within the study area. These rankings are presented in Table 4.4, which includes the normalized Entropy and AHP weights alongside the computed hybrid weights and the final ranks assigned to each factor.

The results from the hybrid analysis revealed that lineament density retained its position as the most influential factor, with a hybrid weight of approximately 42.3%, highlighting its dominant role in controlling subsurface water movement and the availability of aquifers. This was followed by slope, with a hybrid weight of 23.3%, reflecting its impact on surface runoff and infiltration capacity. Drainage density ranked third with a weight of 16.6%, emphasizing the significance of surface water pathways in facilitating groundwater recharge.

Other factors such as land use/land cover (LULC) and rainfall received moderate weights of 9.7% and 3.5% respectively, suggesting that while they influence groundwater potential, their effect is less pronounced compared to structural and topographic variables. On the lower end of the spectrum, geology and soil were assigned the least weights (2.6% and 2.0% respectively), indicating their relatively uniform spatial distribution or limited discriminative power within the context of the study area.

Table 5: Hybrid Weighting and Final Ranking of Groundwater Conditioning Factors

Rank	Factor	Entropy Weight	AHP Weight	Hybrid Weight
1	Lineament Density	0.4538	0.3922	0.4230
2	Slope	0.2301	0.2349	0.2325
3	Drainage Density	0.2322	0.0996	0.1659
4	LULC	0.0713	0.1218	0.0965
5	Rainfall	0.0125	0.0584	0.0355
6	Geology	0.0002	0.0522	0.0262
7	Soil	0.0000	0.0409	0.0204

The integration of both methods into a single hybrid weighting scheme allows the model to benefit from the objectivity of statistical analysis and the contextual relevance of expert insights. By ranking the factors based on these hybrid weights, a more comprehensive and defensible assessment of groundwater potential was achieved. The final hybrid weights were subsequently applied in the weighted overlay analysis within the GIS environment to generate the Groundwater Potential Index (GWPI) map, which delineates zones of varying groundwater suitability across Owerri, Imo State.

3.4 Analysis of Groundwater Potential Zonation Results

Following the weighted overlay analysis using the standardized and reclassified conditioning factors, the final groundwater potential map of Owerri, Imo State, was categorized into five distinct groundwater potential zones. These zones include Very Low, Low, Moderate, High, and Very High Potential areas, based on the computed Groundwater Potential Index (GWPI). The spatial extents of each zone were calculated in square kilometers and are presented alongside their corresponding percentage coverage in Table 6.

The analysis of the results indicates that the Moderate Potential Zone occupies the largest portion of the study area, covering approximately 2,812.65 hectares, which corresponds to 48.84% of the total land area. This dominant class suggests that the region exhibits moderately favorable conditions for groundwater accumulation and recharge. The prevalence of this class is attributed to the relatively balanced distribution of slope, land cover, drainage, and structural features that collectively provide moderate infiltration and storage capacity.

The Low Potential Zone is the second most extensive, accounting for 2,365.59 hectares or 41.08% of the area. This zone reflects areas where groundwater occurrence is limited by factors such as steep slopes, dense drainage networks, low lineament densities, or impervious land cover. While groundwater may still be present in these areas, its availability is likely to be lower and more spatially restricted.

The High Potential Zone covers 503.66 hectares, representing 8.75% of the study area. These areas are characterized by high lineament densities, low drainage densities, gentle slopes, and favorable land use types such as vegetation or water bodies, all of which facilitate groundwater recharge and storage. Although relatively limited in extent, these high-potential areas are critical for sustainable groundwater development and should be prioritized in well drilling and groundwater exploration programs.

The Very High Potential Zone, while the least extensive, still covers 75.46 hectares, amounting to 1.31% of the total land area. These zones are considered the most promising for groundwater exploitation due to optimal geohydrological conditions that enhance recharge, movement, and retention. These include intersecting lineaments, flat terrain, permeable soils, and proximity to recharge sources such as rivers or rainfall concentration zones. Despite their limited spatial coverage, these zones offer strategic importance for groundwater infrastructure planning, especially in densely populated or water-scarce communities.

In contrast, the Very Low Potential Zone occupies only 1.73 hectares, equivalent to a mere 0.03% of the study area. These areas are characterized by impermeable lithologies, high slopes, dense built-up surfaces, or geological formations that limit infiltration and groundwater movement. The negligible extent of this class indicates that such unfavorable conditions are rare within the Owerri landscape.

Table 6: Area Coverage of Groundwater Potential Zones

Groundwater Potential Zone	Area (km²)	Percentage (%)
Very Low Potential	1.73	0.03
Low Potential	2,365.59	41.08
Moderate Potential	2,812.65	48.84
High Potential	503.66	8.75
Very High Potential	75.46	1.31

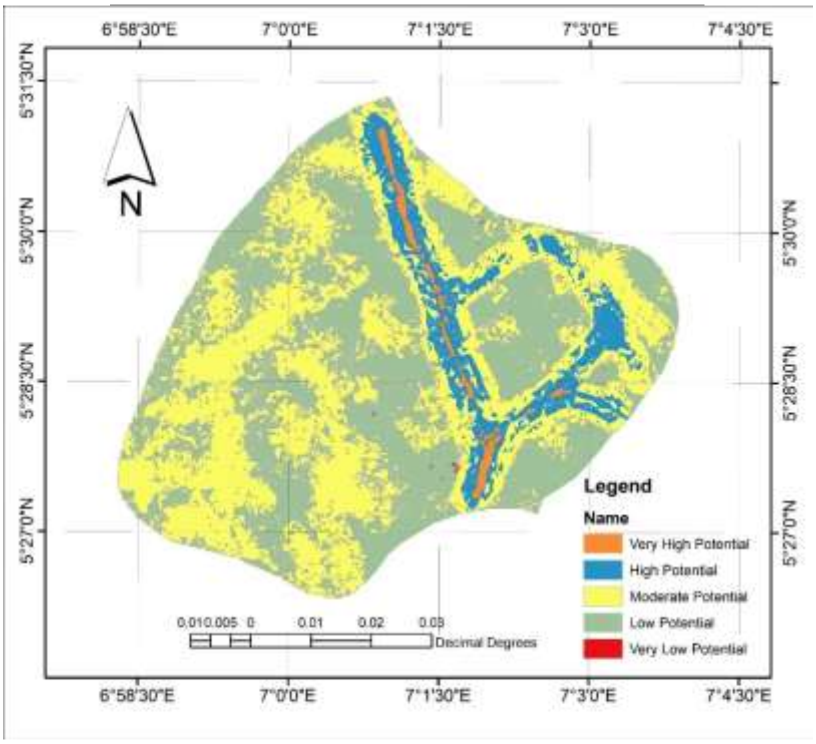

Figure 15: Ground Water Potential Zones in Owerri Municipal

The spatial distribution of groundwater potential classes in Owerri has significant implications for urban water resource management, borehole siting, and sustainable groundwater development. The dominance of the Moderate and Low Potential Zones, covering nearly 90% of the total area, suggests that while groundwater resources are moderately available across most parts of the region, careful site-specific evaluation is necessary to ensure optimal yield and sustainability.

The relatively small but strategically important High and Very High Potential Zones should be considered priority zones for water supply development, especially in peri-urban and rural communities lacking surface water infrastructure. These zones could also serve as groundwater conservation areas for future resilience planning, particularly under increasing pressure from urban expansion and climate variability.

Conversely, the Very Low Potential Zones, although spatially minimal, should be avoided for groundwater infrastructure investments due to the high likelihood of poor yields or dry boreholes. Such areas may be more suitable for alternative land uses that do not rely heavily on groundwater abstraction.

4. Conclusion

This study has provided a comprehensive assessment of groundwater potential in Owerri Municipal, Imo State, using GIS and remote sensing techniques coupled with a hybrid multi-criteria decision-making approach. By integrating thematic layers such as slope, land use, geology, soil, rainfall, lineament, and drainage density, the study successfully delineated zones of varying groundwater potential across the municipality.

The application of both Entropy and AHP weighting methods enabled a robust evaluation of the relative importance of each conditioning factor. The hybrid model, combining objective and subjective evaluations, resulted in a balanced and more defensible weighting system, improving the reliability of the final groundwater potential map.

The findings indicate that a substantial proportion of the study area (approximately 90%) falls under Moderate and Low potential zones, while only a small fraction constitutes high-yield aquifer zones. This has important implications for water supply development, especially in the face of growing urban demand and limited surface water availability.

The study demonstrates that GIS-based groundwater potential mapping is a valuable tool for spatially identifying suitable zones for borehole development, aquifer recharge protection, and groundwater sustainability planning. It offers a scalable framework that can be adapted for other regions with similar hydrogeological characteristics.

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