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GIS-Based Assessment of Groundwater Potential Zones in Lokoja Metropolis, Kogi State, Nigeria Using Remote Sensing and Analytical Hierarchy Process.

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ABSTRACT

Groundwater is essential for human survival but faces threats like contamination from agriculture, industry, domestic activities, over-extraction, and climate change impacts. These challenges cause health risks and water scarcity, affecting socio-economic stability. This study aimed to assess groundwater potential zones in Lokoja metropolis, Kogi State, Nigeria. With a view to provide relevant information for the sustainability and management of groundwater resources. Data used are Landsat 8 OLI satellite images, Digital Elevation Models, rainfall data, soil and geological map. The Analytical Hierarchy Process (AHP) evaluated factors influencing groundwater, including geology, rainfall, lineament and drainage density, slope, elevation, soil, and land use, with groundwater potential zones mapped via Weighted Index Overlay Analysis in ArcGIS. The zones were classified from very low to very high potential. The very low zone covers 14.01% of the area, mainly amphibole schist; low potential (24.02%) aligns with granite and charnockite; moderate (24.93%) with migmatite; high (23.75%) with sandstone and siltstone; and very high (13.24%) with undifferentiated alluvium, concentrated centrally. Geology was the most influential factor (37%), followed by lineament density (18%). The west showed very high potential due to dense lineaments and flat terrain, while the east had lower potential. The study recommends that government may provide alternative water sources in low potential areas to address water scarcity.

Keywords: Groundwater, RS, GIS, AHP, GWPZ.

1.0 INTRODUCTION

1.1 Background to the Study

About ninety six percent of fresh water used today is groundwater (IAH, 2026; SDWF, 2026) and its purity meets need in rural and urban areas and supports economic growth (Abanyie et al, 2023). Groundwater remains preferred due to cost-efficiency and resistance to drought and pollution compared to surface water. The only channel to access this groundwater is through the drilling of boreholes with specialized equipments (United Nations, 2023). The advancement of Remote Sensing (RS) and Geographical Information System (GIS) technologies has revolutionized hydrogeospatial studies. RS, is a valuable tool in understanding the various factors influencing groundwater occurrence (Ibrahim et al, 2024). It does that by the interpretation of satellite data

especially in regions lacking accurate geologic and cartographic information (Jessica et al, 2024). RS and GIS offers baseline information on soils, land use, vegetation, surface and groundwater, geology, landforms, topography, and settlements, complementing groundwater data (Nxumalo et al, 2026).

This study is beneficial because it could give water planners and local decision makers a clear, spatially explicit picture of where groundwater is abundant and where it is risky to use. It protects high potential zones, restricting overuse in low potential ones and focusing monitoring on areas where quality is worse. In short, this study shows where water is available, where it is safe and where intervention is needed (Francis et al., 2024).

Moshe and Beza (2024) disclosed that the knowledge of groundwater potential zones is significant in transforming groundwater from a hidden and unpredictable resource into one that can be managed with foresight and precision. Groundwater provides a large portion of the world's fresh water, yet without understanding where it is most likely to occur, efforts to access it often become inefficient and costly. (Bhangaonkar R. and Fennell, 2022) highlighted that mapping potential zones using tools like GIS and multicriteria decision analysis allows planners to see which parts of a landscape are likely to hold usable water and which are not.

What necessitated this study is the fact that, Lokoja faces a persistent water crisis driven by frequent borehole failures and pump malfunctions, largely caused by poor siting and low yields. Rising population and limited access to pipe-borne and surface water have pushed greater reliance on groundwater, yet many wells are abandoned due to inadequate knowledge of productive zones and the high cost of geophysical surveys. As a result, people turn to unsafe sources like contaminated wells and rivers, increasing risks of typhoid, cholera, and dysentery hence, this study aimed to conduct a GIS-Based Assessment of Groundwater Potential Zones in Lokoja Metropolis, Kogi State, Nigeria Using Remote Sensing and Analytical Hierarchy Process with the objectives of examining the factors influencing groundwater potential of Lokoja metropolis and determining the relationship between existing borehole yield and the groundwater potential zones.

2.0 THEORETICAL FRAMEWORK

2.1 Geographic Information System and Remote Sensing

GIS has proven to be an effective tool for groundwater potential zonation, particularly when employed through an integrated approach (Francis et al., 2024). GIS has evolved into a powerful instrument for managing, integrating, and analyzing digital geographic data from diverse sources, enabling the solution of complex problems. Additionally, remote sensing provides valuable multi-spectral, multi-temporal, and multi-sensor data on the Earth's surface, contributing significantly to hydrological investigations, and its integration with GIS generates spatial and temporal information essential for accurate prediction and validation (Nxumalo et al, 2026).

2.2 Analytical Hierarchy Process (AHP)

Alharairi et al (2025) explained the Analytic Hierarchy Process (AHP), is a structured method for organizing and analyzing complex decisions. Developed by Thomas L. Saaty in the 1970s, it brings together mathematics and psychology to help people identify the option that best aligns with their goals and understanding of the problem. The AHP uses pairwise comparison to calculate weight based on the influence each criterion has on the occurrence of groundwater. Foss and Klein (2023) explained that the process of AHP starts by breaking a complex decision into a hierarchy of smaller, more manageable parts. Mousav et al (2025) described how people use AHP because it handles both tangible and intangible factors in the same framework. One can weigh hard data like cost alongside softer considerations like comfort or brand reputation. It also reduces bias by forcing

individuals to justify each comparison, preventing one factor from dominating without reason. For group decisions, AHP offers a transparent structure that lets team members negotiate and merge different viewpoints into a shared consensus.

2.3 LITERATURE REVIEW

2.3.1 Examining the factors influencing groundwater potential

Epuh et al. (2020) used remote sensing, geographic information systems (GIS), a multi-criteria approach, and hydro geophysics to define the groundwater potential zone in Ondo State. The thematic maps used for the project were sourced from; Landsat 8, the US Geological Survey's Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) with 30m, the Geology Map of Nigeria and the Tropical Rainfall Measuring Mission's (TRMM) rainfall data.

The authors used Spatial Analysis tool in Arc GIS 10.5 to overlay these maps using the weighed overlay approach. The result showed that, 17.5% of the entire study area is in the "very high" potential zone, 12.0% is in the "high," 39.5% is in the "moderate," 25.7% is in the "low," and 5.3% is in the very low potential zone. The "very low" prospect zone is mostly located in the basement complex zone in the northern portion of the study region, whereas the very high prospective areas are located in the sedimentary zone with large alluvial deposits in the southern half of the study area. Top soil, sand (which includes fresh water), sand clay (which contains brackish water), and clay (which contains saline water) are the four lithologies found in the Ijapo Vertical Electric Sounding (VES) data analysis query findings.

Jude et al. (2022) investigated groundwater potential zones in the Federal Capital Territory, Abuja, Nigeria, using an Analytical Hierarchy Process (AHP) and multi-criteria decision analysis. In terms of the methodology used, the study area's geology map was scanned, georeferenced, and digitalized from the Nigeria Geological Survey Agency's geologic map; the Shuttle Radar Topography Mission (SRTM) and Digital Elevation Model (DEM) with a 30-meter resolution was used. Monthly rainfall data spanning 15 years, from 2006 to 2020, was obtained from the Nigerian Meteorological Agency (NIMET). Sentinel-2 with 10-m spatial resolution of 2020 from the ESRI portal. The occurrence and flow of groundwater are thought to be significantly influenced by seven elements, which led to the creation of seven thematic maps. Geology, slope, drainage density, rainfall, land-use/land-cover, lineament density, and soil type are some of these variables. Based on the different relative contributions to groundwater occurrence and movement, the thematic maps were given normalized weights using the Analytic Hierarchy Process (AHP). The MCDA was subsequently implemented using the Weighted Overlay tool, which was used to process these thematic maps in a GIS environment. Five classifications were created from the area's resulting Groundwater Potential Zones (GPZ): Very good, Good, Moderate, Poor, and Very Poor. These classes represent 19%, 8%, 14%, 47%, and 13% of the total.

Moshe and Beza (2024) reiterated that the groundwater potentials of the study area was categorized into five classes, which are; very low, low, moderate, high, and very high. The result of the analysis conduct showed that, most areas of the study area are discovered to be under the moderate category and it covers around 540.23 km2 which constitutes 65.6% of the study area, whereas very low, low, high, and very high potentiality classes cover 0.002, 10.99, 21.93, and 0.55% of the area, respectively. When comparison was done, it was established that 92% of the monitored boreholes aligned with the developed map.

Ejepu (2020) used remote sensing, GIS, and multicriteria decision analysis tools to evaluate the groundwater potential zone in the Upper Niger River Basin Development Authority area. The data used were geological map, the land-use/land-cover map, rainfall data, SRTM DEM and the digital soil map. The methodology employed were Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) approaches. In order to do this, seven factors such as

geology, lineament density, slope, drainage density, rainfall, land-use/land-cover, and soil class thought to have a major influence on the occurrence and movement of groundwater were created. The Analytic Hierarchy Process (AHP) was used to standardize these elements' respective contributions to groundwater occurrence and assign weights to them. The result led to the classification of groundwater potential zones into four categories: Very good, Good, Moderate, and Poor, which correspond to 7%, 27%, 43%, and 23% of the total. As a first guide when choosing probable locations for in-depth groundwater resource exploitation, this result shows the area's groundwater potential.

2.3.2 Relationship between existing borehole yield and the groundwater potential zones

Shinde et al. (2022) explained that the map produced by GIS-AHP/AUC was compared against real borehole yields. Higher yield boreholes fall in zones predicted as "good" or "very good" potential, and low-yield boreholes in "poor" zones. The authors used ROC-AUC to quantify how well the model's predicted zones match the observed borehole yields.

Adaviruku et al. (2023) examined the spatial correlation between borehole yields and groundwater potential zones in the Okene local government area of Kogi State, Nigeria. For this investigation, a variety of data collected from various sources were employed. These include rainfall data from PERSIANN, a geological map from NGSA, a Sentinel 2 satellite picture with a resolution of 10 m, a Digital Elevation Model from the USGS, and borehole yield data from Aquatech Drilling Services and ATK Water. In order to generate different zones of groundwater potential, the various factors that influence the occurrence of groundwater (rainfall, lineament density, geology, drainage density, land use/land cover, and slop) were weighted with the aid of AHP. The relationship was then tested using Pearson correlation and validated using current borehole yields. According to the study's findings, the low potential zone encompasses 33.2% of the territory, the intermediate potential zone (44.9%), which spans the whole Okene LGA, and the high potential zone (21.9%), which is primarily located in the western portion of the region. 0.919 was the outcome of a strong positive correlation (R) analysis using Pearson moment correlation. The groundwater potentiality map generated by the analysis and the current borehole yields in the research region have a substantial positive correlation, according to the correlation value.

Ajay et al. (2020) used remote sensing, GIS, and AHP techniques to identify groundwater potential zones in a portion of Maharashtra, India's Deccan Volcanic Province (DVP). Geology, geomorphology, soil maps, Landsat-8 satellite images, and space radar topographic mission (SRTM /DEM) data were among the sources of information. Five groundwater potential zones were identified by applying the Analytic Hierarchy Process in ArcGIS to weight, rank, and reclassify maps into very poor (11.77%), poor (21.73%), moderate (30.13%), good (25.34%), and very good (11.02%). Sensitivity analysis revealed slight variations in lineament density, LULC, and slope in the very poor to poor potential zones. Validation was done using rainfall, groundwater level fluctuations, and well yields. The results showed that the good to very good zones had larger yields (5.94 to 14.88 l/s) than the poor to very poor zones (0.38 to 1.37 l/s). Planning for sustainable groundwater management was aided by cross-correlation coefficients, which showed a good link between rainfall, groundwater level, and the groundwater potential index ($R2 = 0.84$).

Ümit (2021) used GIS and multi-criteria decision-making tools to identify groundwater potential zones: Upper Coruh River Basin (NE Turkey) case study. Slope, topographic wetness index, geomorphology, drainage density, lithology, lineament density, rainfall, soil type, soil thickness, and land-use classes were among the ten geoenvironmental elements that were taken into consideration as decision criteria. Layer development, analysis, and standardization were done using GIS tools. Areas are mapped into very high potential, high potential, moderate potential, low potential, and very low potential using the derived groundwater potential zones. According to the study, the basin's groundwater potential is high to very high in 21.5% of cases, extremely low to low in 57.15%, and moderate in 21.4% of cases. Strong agreement between the groundwater

potential zone classes and the local data was shown by the model validation, which used well discharge and groundwater depth data from 22 wells.

2.0 METHODOLOGY

2.1 Overview of Study area

Guma et al, (2025) described Lokoja metropolis as situated between latitudes 7°45′N and 7°51′N and longitudes 6°41′E and 6°45′E within the lower Niger-Benue trough, covering about 3,180 km² (Macrotrends, 2022). The metropolitan population was estimated at 791,000 in 2022 and is projected to reach 931,000 by 2025. It borders Kogi LGA to the north, Kabba-Bunu LGA to the west, Bassa LGA to the east, and Adavi and Ajaokuta LGAs to the south.The area experiences a warm continental climate classified as Koppen-Aw. Rainfall occurs from March/April to October/November with a brief dry spell in August. Temperatures rarely fall below 30.7°C, peaking in February and March. Relative humidity averages 30% in the dry season and 70% in the wet season. Winds blow at 3.0–4.6 knots from the south-southwest in June-July and 1.5–3.7 knots from the northeast in December-January. Audu, (2012) and Guma, et al (2025) also described that the climate change of the study area is intensifying rainfall variability, prolonging droughts and floods, and affecting groundwater availability. Vegetation is mainly Guinea savanna with tall grasses and scattered trees like shea butter, oil bean, and locust bean. Seasonal burning and human activity have degraded natural vegetation. This affects aquifer recharge by reducing infiltration and increasing evapotranspiration. Soils are sandy over weakly organized clay, with hydromorphic alluvial and colluvial deposits along floodplains. Soil porosity and permeability strongly influence recharge rates. Geologically, the area lies on the Precambrian Basement Complex, dominated by migmatite-gneiss and older granite, with Cretaceous sediments in the north. Permeable formations enhance infiltration, while crystalline rocks promote runoff (Benjmel et al., 2020). Drainage is dominated by the Niger and Benue rivers, with groundwater in crystalline rocks dependent on weathering and fracturing. Relief ranges from 300 m at the confluence to 600 m in uplands, with Mount Patti and the Agbaja Plateau as prominent features. Topography influences runoff and recharge. Population growth accelerated after Lokoja became Kogi State capital in 1991, rising from 77,516 in 1991 to 195,261 in 2006 (NPC, 2006). The city hosts diverse ethnic groups, creating high demand for sustainable water supply

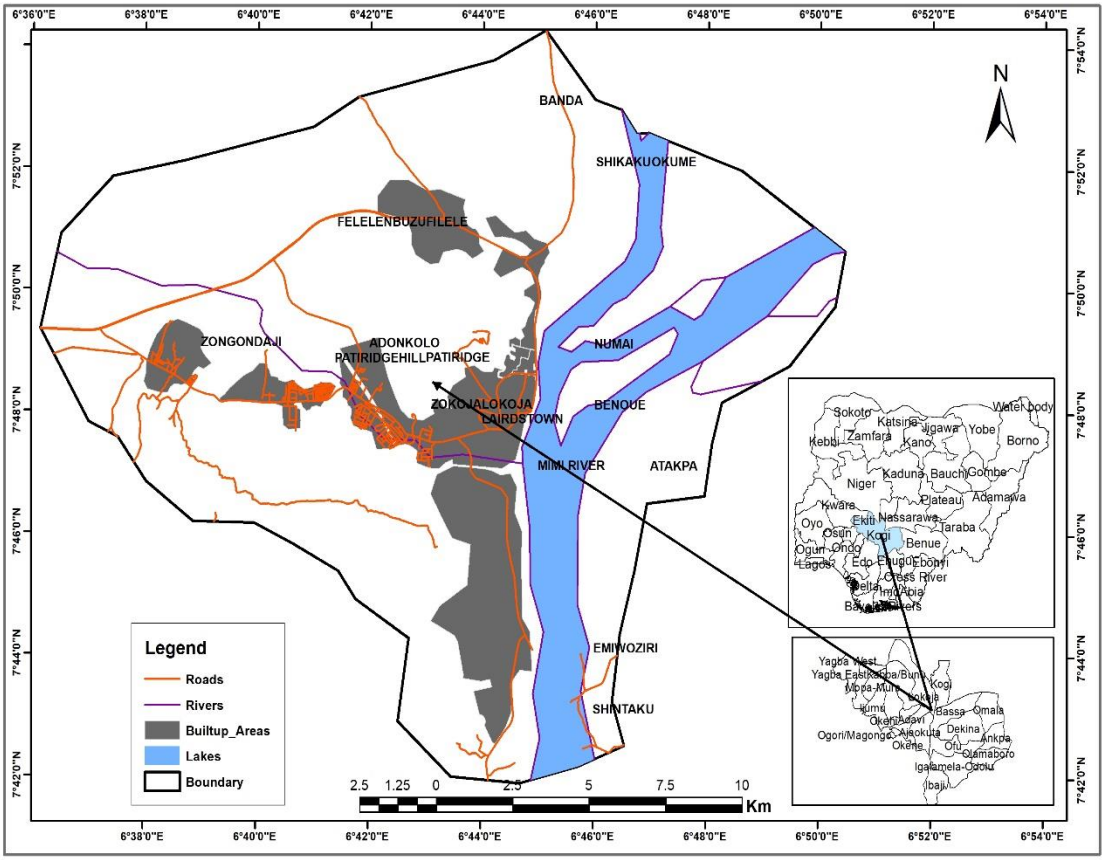


Figure 3.1: Lokoja Metropolis
Source: - Modified from Administrative Map of Kogi State 2024

3.2 Methodology

3.2.1 Data used

The study began with a reconnaissance survey and field observations to familiarize the researcher with the study area. Information was gathered from the Great Lokoja Water Works office, and a base map was obtained from the surveyor general's office in Lokoja. Rainfall data was obtained from the Nigerian Meteorological Agency (NiMet) office in Lokoja. Both the primary and secondary data were utilized in this research, the primary data that were used are satellite imageries (Landsat 8 and Shuttle Rader Topographic Mission, (SRTM) and the secondary data comprises of rainfall data and existing geological and soil maps of the study area with the administrative map and geographical coordinates of dug wells/yields in Lokoja metropolis.

3.3 Data Processing

The study area was clipped from the Landsat 8 OLI and SRTM images using the "Arc Toolbox with an Analysis Tool" function in ArcGIS 10.5. Since the images had already been ortho-rectified, radiometric corrections were not necessary. However, the images were geometrically corrected to the Universal Transverse Mercator (UTM) projected coordinate system to zone 32N using ArcGIS 10.5. The administrative, geology, and soil maps of the study area were scanned using an A0 scanning device to convert them from analogue to digital format. The scanned maps were then imported into the ArcGIS environment for georeferencing. The satellite images underwent

georeferencing, aligning them with real-world coordinates within a GIS environment. Specifically, the images were rectified to the Universal Transverse Mercator (UTM) zone 32N projection, ensuring consistent coordinates. Geology, administrative, and soil maps were also georeferenced to this common coordinate system. This process standardized the satellite images to a uniform 30-metres resolution, enabling accurate overlay analysis.

A typical Landsat scene covers an area of approximately 185 km by 185 km. The synoptic view provided by remote sensing allows it to capture large areas, with the images typically comprising multiple bands. To focus on the area of interest (AOI), which is the Lokoja metropolis, image sub-setting was performed. This sub-setting was done in the ArcGIS (ArcMap) environment using the spatial analyst tool. Digitizing in GIS involves tracing information from images or maps in a geographically accurate manner to convert analogue data into a digital format for further processing and analysis. For this study, digitization was performed on the geology, soil, and administrative maps to delineate the necessary boundaries and features. This process was carried out within the ArcGIS environment. Rasterization is the process of converting an image from vector format to raster format. To perform a suitable assessment using the Analytical Hierarchical Process (AHP) in a GIS environment, all the selected factors influencing groundwater potential zones in the study were converted to raster formats. This rasterization was carried out in the ArcGIS environment using the conversion tool.

ArcGIS software was employed for pixel-based classification. Supervised classification was conducted using Maximum Likelihood Classification (MLC) to produce the landuse and land cover map of the study area. The classified the landuse landcover of the study area into five namely; built up area, vegetation, bare surface, water body and shrub this is because these classes are evident, discernable and recognizable on the satellite image for the study area. Table 3.2 shows the landuse categories of features into classes and the descriptions of details in the various classes that were used to perform the supervised classification.

Table 3.2: Land use and Land Cover Classification Scheme of Lokoja Metropolis

Code	Land Use Categories	Description
1.	Built-up Areas	Land used for residential, transportation and communication purposes.
2	Water body	Areas covered by the body of water e.g., rivers, streams, ponds and dams.
3	Vegetation	Land covered with natural vegetation that is Predominantly grasses.
4	Bare surface	Exposed soils, land devoid of vegetal cover.
5	Shrubs	Open areas covered in homogeneous grasses with little to no taller vegetation.

From an existing geological map of Nigeria obtained from the Nigerian Geological Survey Agency, the research area's geological map was scanned, georeferenced, and digitalized. To enhance feature extraction, a lineament map was generated from the Digital Elevation Model (DEM) of the study area. This involved creating hill shade models at varying azimuth and altitude ratios (315:45,

200:50, 150:65, and 100:60) to optimize the extraction of linear features. The next step was to manually digitize the lineaments onscreen. To create the drainage density map, the ArcGIS spatial analyst tool was used to extract this thematic layer from the research area's SRTM/DEM image and convert it to raster. In this study, Digital Elevation Model (DEM) of the study area was prepared using the spatial analyst tool in ArcGIS to produce the slope map of the study area and reclassification into different classes. For this study, rainfall data was gotten in comma separated value format which was imported into the ArcGIS environment. Using the Inverse Distance Weighting (IDW) technique of interpolation the rainfall map for the study area was produced. For this study, the soil map of the research area was prepared by scanning, georeferencing, and digitizing a Nigerian soil map obtained from the Food and Agriculture Organization of the United Nations (FAO, 2001). The DEM was derived from the SRTM and then imported into the ArcGIS environment using Spatial Analysis and reclassification into various classes. In this study, the classification of water bodies, vegetation, rock outcrops, built-up areas, and bare ground was done under supervision. The maximum likelihood classification, which was utilized in this work, is the most widely used supervised classification.

3.4 Data Analysis

3.4.1 Data analysis on the examination of the factors influencing groundwater potential zones in Lokoja metropolis

Each factor (rainfall, lineament density, drainage density, geology, slope soil, elevation and land use/land cover) were analyzed. Thematic map for each of these factors was produced and reclassified into very low, low, moderate high and very high to see the variation of each of these factors across the study area. There was comparison of individual influencing factor and comparison within the criteria to see which factor predominates at any location chosen.

The different factors influencing groundwater occurrence were weighted using the Analytical Hierarchy Process (AHP). The most important criterion for groundwater occurrence have the highest weight while the least importance criterion have the lowest. The thematic map of individual criterion was reclassified using the weight values calculated using the AHP pairwise comparison. The reclassification was done using the spatial analyst tool in ArcGIS. Weight assignment using AHP for the thematic maps were copied out manually see detailed in Table 3.3.

Table 3.3: Procedure of Assigning Weightages in Analytical Hierarchy Process

Scale	Degree of preference	Explanation
1	Equal importance	Two elements contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one element over another.
5	Strong importance	Experience and judgment strongly favor one element over another.
7	Very strong importance	One element is favored very strongly over another.
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation.
2,4,6,8	Value for inverse comparison	Can be used to express intermediate values.

The reclassification criteria for the geology map, slope, and lineament are outlined in Tables 3.4 to 3.7. The values assigned to geology layer in table 3.4 take into account the hydrogeological significance of the rock types. The characteristics considered for geology are: rock type, type and thickness of weathering, fracture density and dykes. However for lack of space, factors such as for Slope, Lineament Density and for Soil are presented in tables 3.5 to 3.7 as extracts.

Table 3.4: Values Assigned for Groundwater Control Parameters for Geology

Parameter	Value	
Geology		
Alluvium	(Very High)	80
Basalt	(Very High)	80
Foliated met.	(High)	70
Metasediments	(High)	70
Granite (syntectonic)	(Moderate)	60
Granite (post tectonic)	(Moderate)	60
Nonfoliate met.	(Moderate)	50
Gneiss	(Low)	40
Laterite	(Low)	40
Kaolinized Granite	(very Low)	10

Table 3.5: Values Assigned for Groundwater Control Parameters for Slope

Parameter	Value	
Slope		
0 -3°	(Very High)	80
4 -7°	(High)	70
8 -11°	(Moderate)	60
12 -15°	(Low)	40
> 15°	(Very Low)	10

Table 3.6: Values Assigned for Groundwater Control Parameters for Lineament Density

Parameter	Value	
Lineament Density		
0 -50 m	(Very High)	80
50 –100 m	(High)	70
100 -150 m	(Moderate)	60
150 -200 m	(Low)	40
200 -250 m	(Very Low)	10

Table 3.7: Values Assigned for Groundwater Control Parameters for Soil

Soil	Weight ages	Rank
Sandy Loam, Sandy Clay Loam,	1	High
Gravelly Sandy Clay	1	High
Sandy Clay, Loam, Gravelly Clay Loam, Kankar Bed	2	Medium
Sandy clay loam	2	Medium
Clay loam	3	Low
Clay	3	Low

3.4.2 Data analysis on evaluation of the relationship between existing borehole yield and the delineated groundwater potential zones in the study area.

The yields of existing boreholes and the values extracted from the Groundwater Potential Map were used to establish the relationship between the two-variable. To validate the groundwater productivity map of the study area showing if the model used was successful, the model by Toyin (2024) was adopted.

$$\frac{T_{bym}}{T_{adb}} \times 100 \qquad 3.6$$

Where $T_{bym}$the total number of coincided borehole with yield map and T_{adb} is the total number of actual drilled boreholes.

4.0 RESULT AND DISCUSSION

The result focused on individual factors influencing groundwater availability, including geology, lineament density, drainage density, slope, rainfall, soil, elevation, and land use/land cover but because of space, only that of geology, lineament density, drainage density, slope shall be presented. After evaluating these factors, groundwater potential zones were determined and mapped, revealing their areal extent. Additionally, the relationship between existing borehole yields and identified groundwater zones was examined.

4.1 Results for factors influencing Groundwater Potentials in the Study Area

4.1.1 Slope

Figure 4.5 was obtained but was classified in figure 4.6 into the following categories: 0-2° (Nearly Flat), 2- 6° (gentle slope), 6 –12° (Moderate slope), 12-20° (Steep Slope), and > 20° (Strong Slope) (See Figure 4.5 and Figure 4.6). The findings showed that, at 46%, the research area's low-slope (0–2°) zones carry the largest weight. Rainwater infiltration is directly impacted by the slope gradient. Because water runs quickly down a steep slope after rainfall, it does not have enough time to enter the surface and replenish the saturated zone, resulting in a reduced recharge when the slope degree (°) rises. As a result, groundwater will occur more readily in places with the lowest slope gradient and less readily in locations with a high slope gradient. For this reason, the slope classes were categorized based on their propensity to contribute to the occurrence of groundwater, ranging from extremely high to very low. The analysis results for different slope classes are presented in Table 4.3.

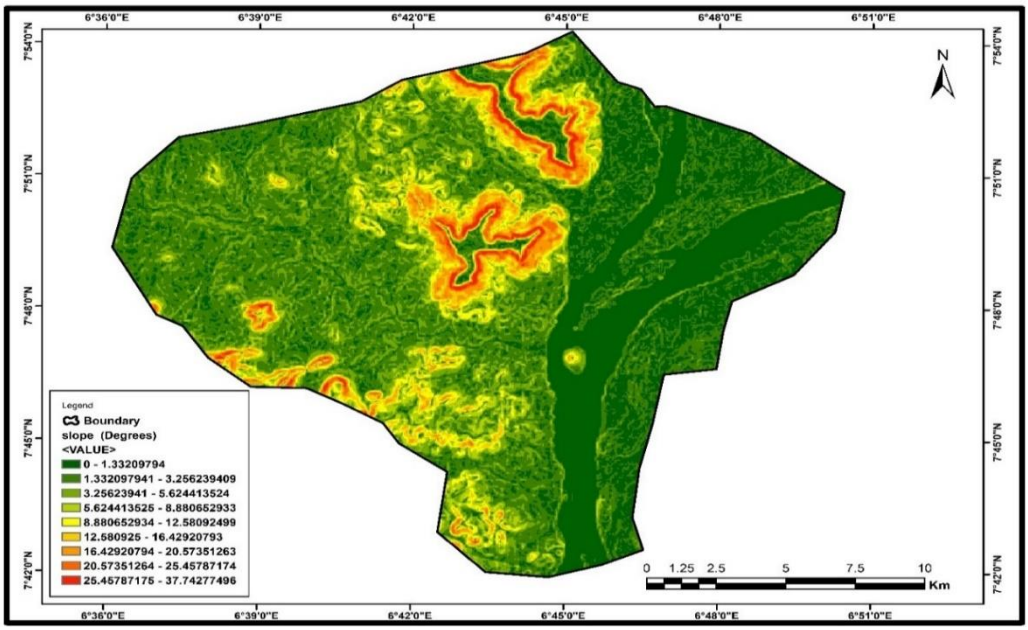


Figure 4.5: Slope of Lokoja Metropolis.
Source: USGS, 2020

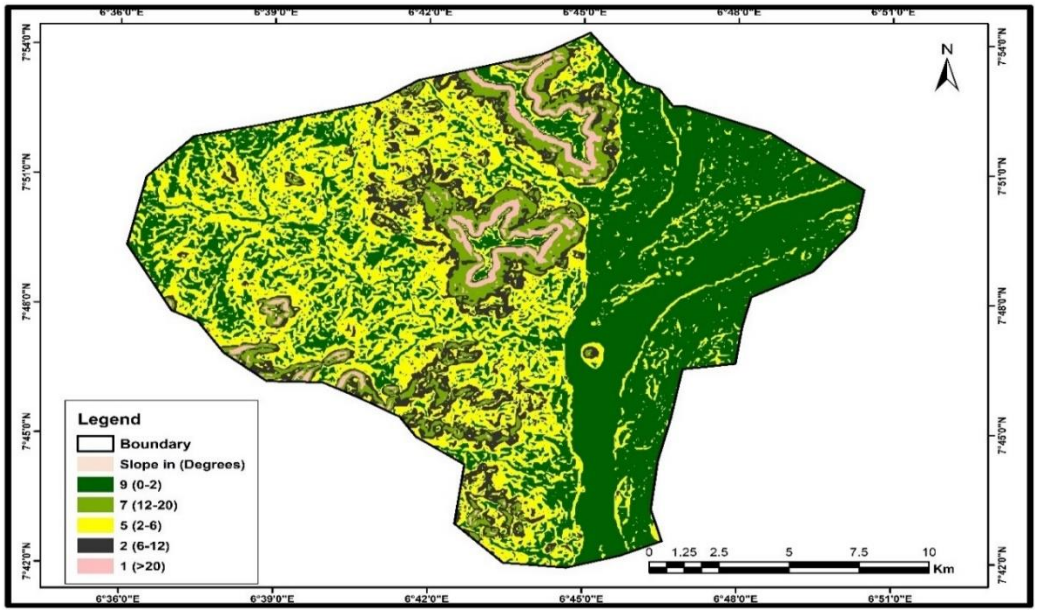


Figure 4.6: Reclassified Slope of Lokoja Metropolis.
Source: Author's Analysis, 2024

Table 4.3: Groundwater potential Based on Slope in Lokoja Metropolis

Slope (°)	Weightage	Potential	%
0-2°	9	Very High	0.46
2-6°	7	High	0.29
6-12°	5	Moderate	0.14
12-20°	2	Low	0.08
>20	1	Very Low	0.03

Source: Author's Analysis, 2024

4.1.2 Drainage density

The drainage network in the study area was generated by on-screen digitization from SRTM data, using the spatial analyst extension in ArcMap 10.5. The drainage density in (km/km²) was computed from the drainage network and it was seen that the highest drainage density (2.5 - 4.6) occurred in the northern, central and southern part of the study area. The different drainage density classes in the study area are as follows: 0-0.4, 0.4-1.0, 1.-1.7, 1.7-2.5 and 2.5-4.6. (km/km²) (see Figure 4.7 and 4.8). The stream pattern in figure 4.8 reflects the rainfall infiltration rate versus surface runoff, influenced by permeability linked to rock type and fracturing. The map showed dense drainage network which typically implies lower permeability that is impacting recharge rates inversely. Areas with high drainage density will not allow for adequate infiltration of water as can be seen from Table 4.4 and had the lowest weight of 6%. On the contrary, areas with drainage density between 0-0.4 had the highest weight of 55% and as a result highest potential for groundwater occurrence which aligns with the fact as established by Ibrahim et al (2026) that, any drainage density that is inversely related to permeability is a crucial factor in assessing groundwater potential zones. The result of the drainage density classes can be seen in Table 4.4.

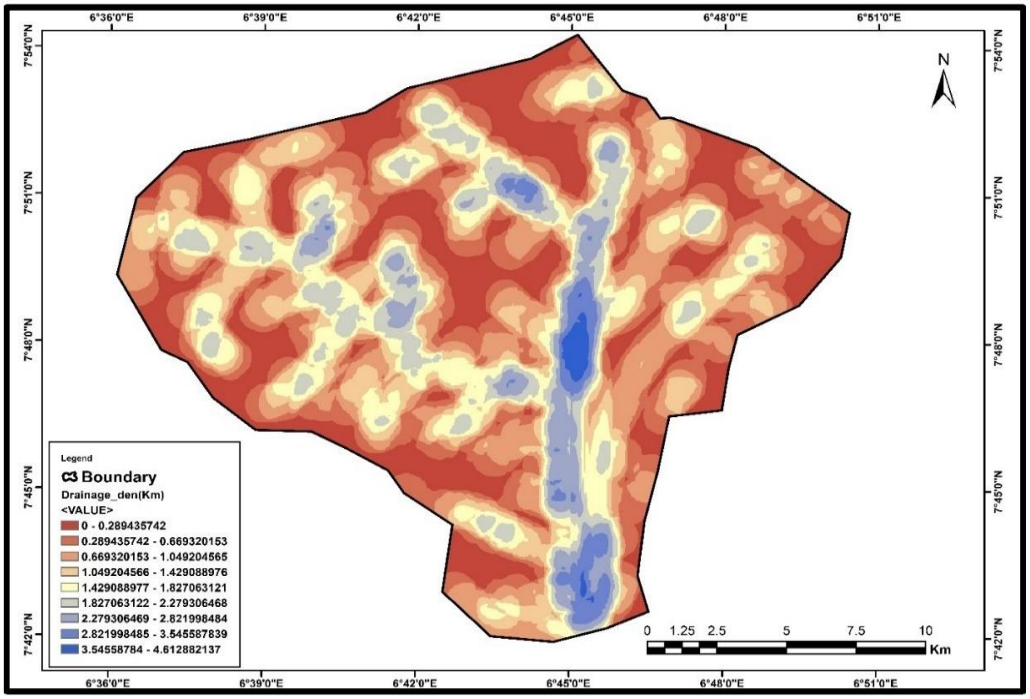


Figure 4.7: Drainage Density of Lokoja Metropolis.
Source: USGS, 2020

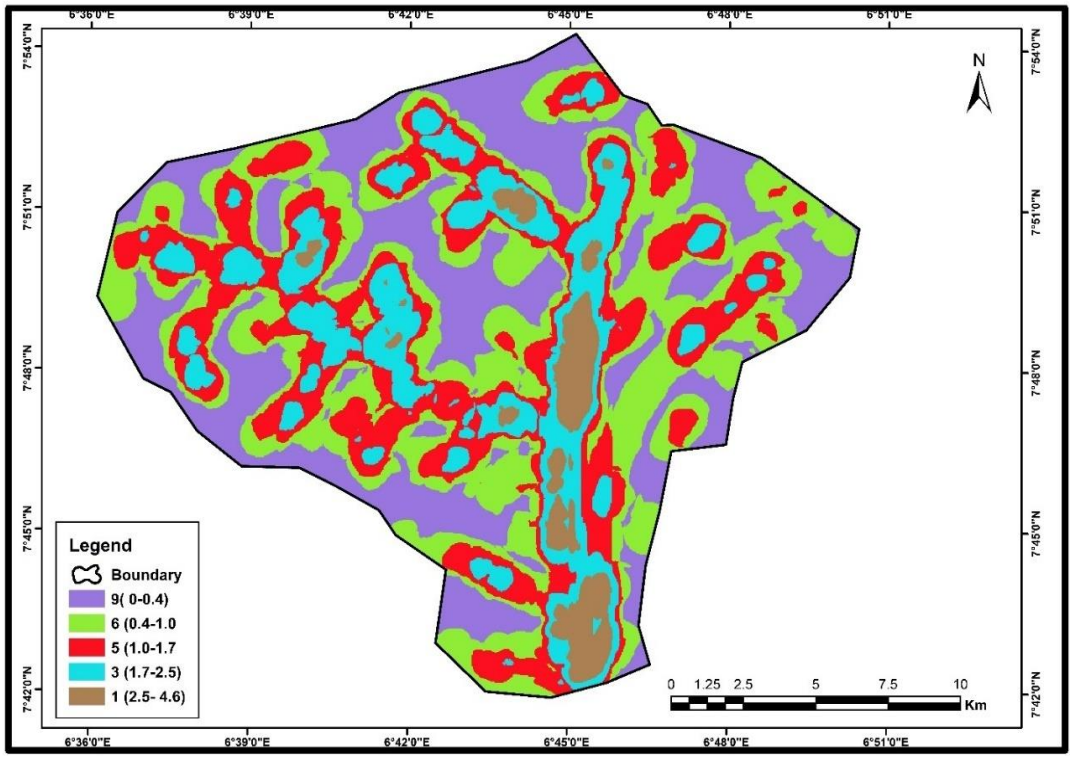


Figure 4.8: Reclassified Drainage Density of Lokoja Metropolis.

Table 4.4: Groundwater potential Based on Drainage Density in Lokoja Metropolis

DD (km/km²)	Weightage	Potential	%
0-0.4	9	Very High	0.55
0.4-1.0	6	High	0.18
1.0-1.7	5	Moderate	0.12
1.7-2.5	3	Low	0.09
2.5-4.6	1	Very Low	0.06

Consistency Ratio= -0.05
Source: Author's Analysis, 2024

4.1.3 Lineament and lineament density

From 4.10 it could be seen that the lineament density ranges from 14.20 km/km² (covering 4.25% of the area) to more than 123.23 km/km² (covering 37% of the area). Notably, areas with high lineament density can have significant groundwater potential, even in hilly regions where groundwater is typically scarce. A large portion of the study region, including Felele and GRA, consisted of areas with zero to 0.2 lineaments, which accounted for 36.06% of the total study area. The grouping of the lineament's density follows; 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.9 and 0.9-1.8. (km/km² (see Figure 4.9 and Figure 4.10). Lineaments, characterized by localized weathering and increased permeability, play a crucial role in groundwater flow and yield. Large lineaments, often associated with shear zones or major faults, can extend from hilly to alluvial terrain, potentially forming productive groundwater reserves.

Lineament is one of the major sources of secondary porosity. The areas with high lineament density were seen to have the highest weight 40% while that of low density had the lowest with 4%. These areas with high lineament density will allow for the easy recharge of the underlying aquifers, which will make such areas favorable for groundwater occurrence.

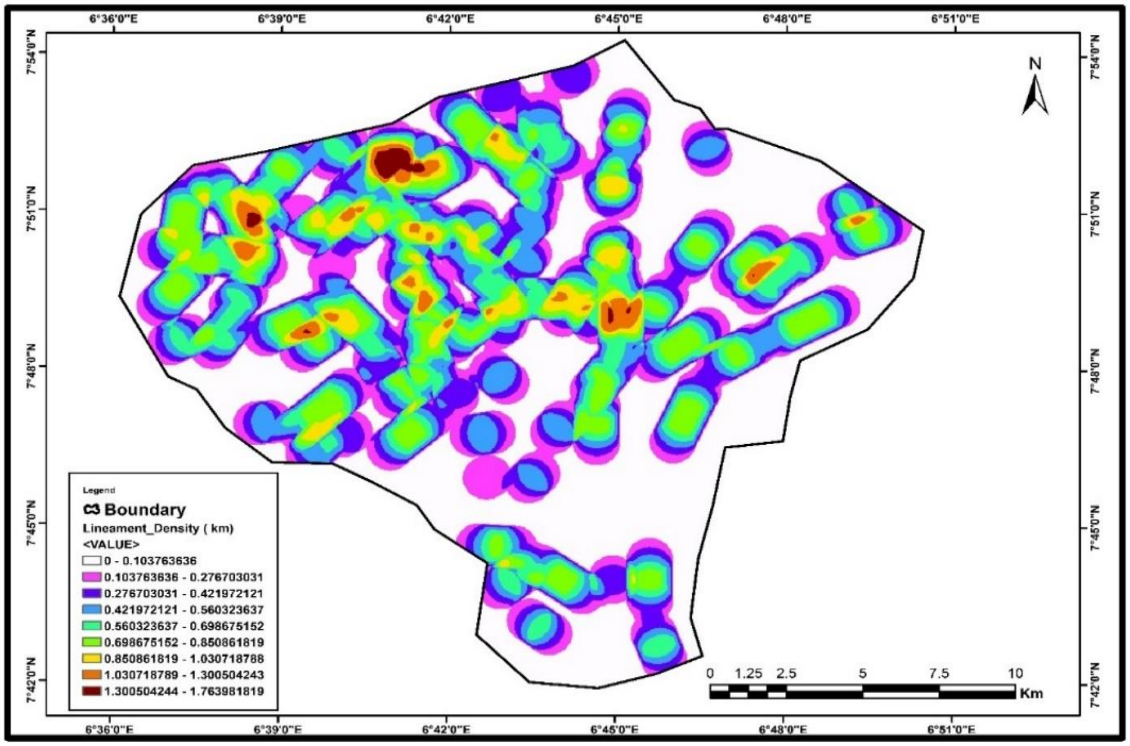


Figure 4.9: Lineament Density of Lokoja Metropolis.
Source: USGS, 2020

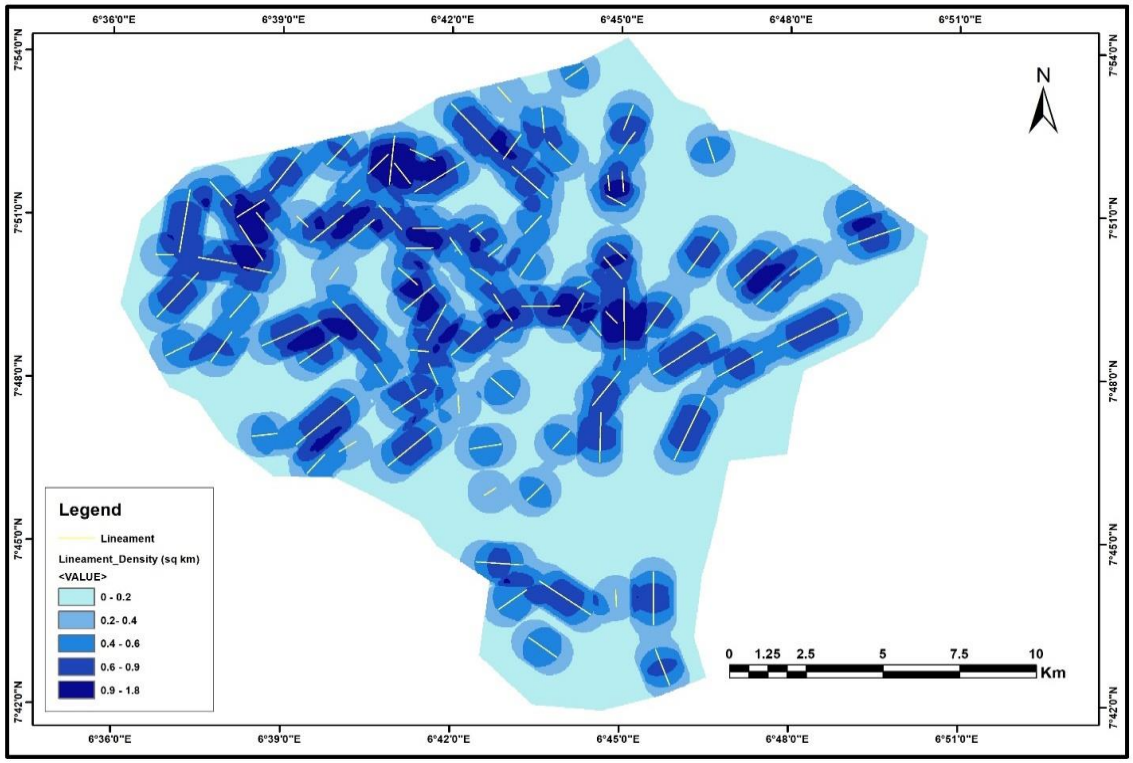


Figure 4.10: Reclassified Lineament Density of Lokoja Metropolis.
Source: Author's Analysis, 2024

The result and weighting of the various lineament density classes were presented in Table 4.5.

Table 4.5: Groundwater potential Based on Lineament Density in Lokoja Metropolis

LD (km/km²)	Weightage	Potential	%
0-0.2	1	Very Low	0.04
0.2-0.4	2	Low	0.10
0.4-0.6	3	Moderate	0.14
0.6-0.9	7	High	0.32
0.9-1.8	9	Very High	0.40

Consistency Ratio=0.05
Source: Author's Analysis, 2024

4.1.4 Rainfall

The mean rainfall for twelve years between (2010 and 2022) was used to generate an average rainfall map of the study area (see Figure 4.3). The years selected was based on the need to assess the current effect of rainfall on the study area. Rainfall is the major source of water used in recharging aquifers. The spread of rainfall in the study area were as follows 1127mm-1137, 1137mm-1144, 1144mm-1152, 1152mm-1162 and 1162-1178mm respectively (see Figure 4.4). The southern part of the study area received the highest mean annual rainfall with an average range of 1162-1178 mm while the lowest was seen in the north with an average of 1127-1137 mm suggesting a humid tropical terrain with the entire study area receiving more than 1,000 mm of rainfall annually. The higher the rain fall received in an area the more the amount of water available to recharge the aquifers.

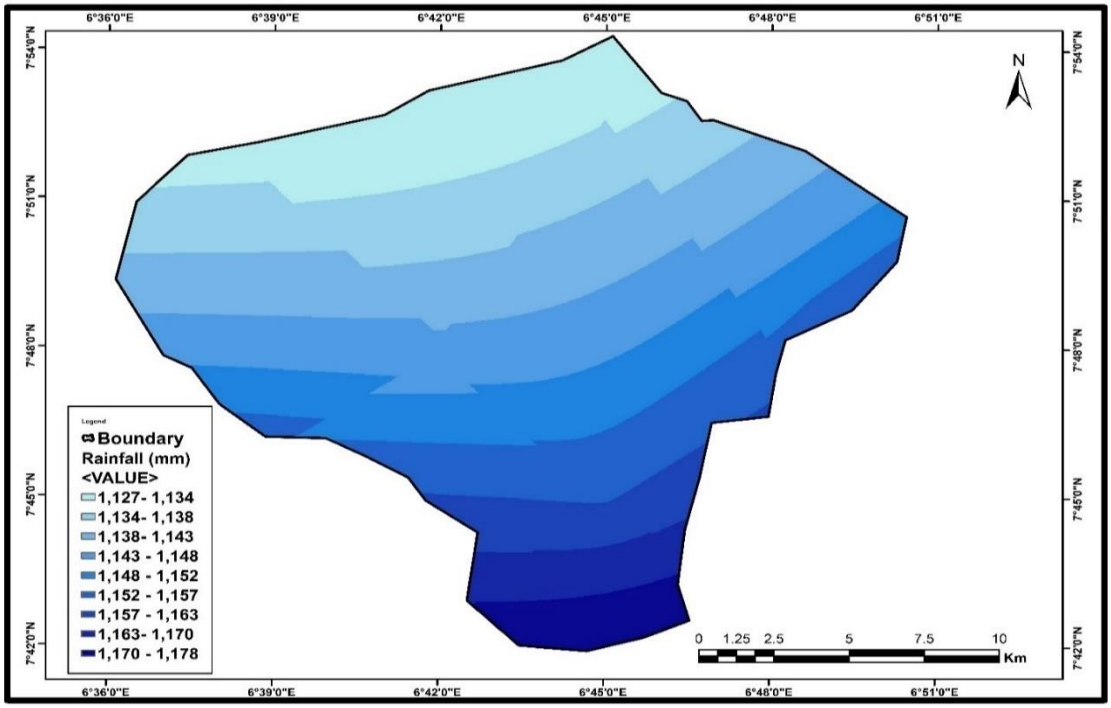


Figure 4.3: Rainfall of Lokoja Metropolis.
Source: NIMET (2022)

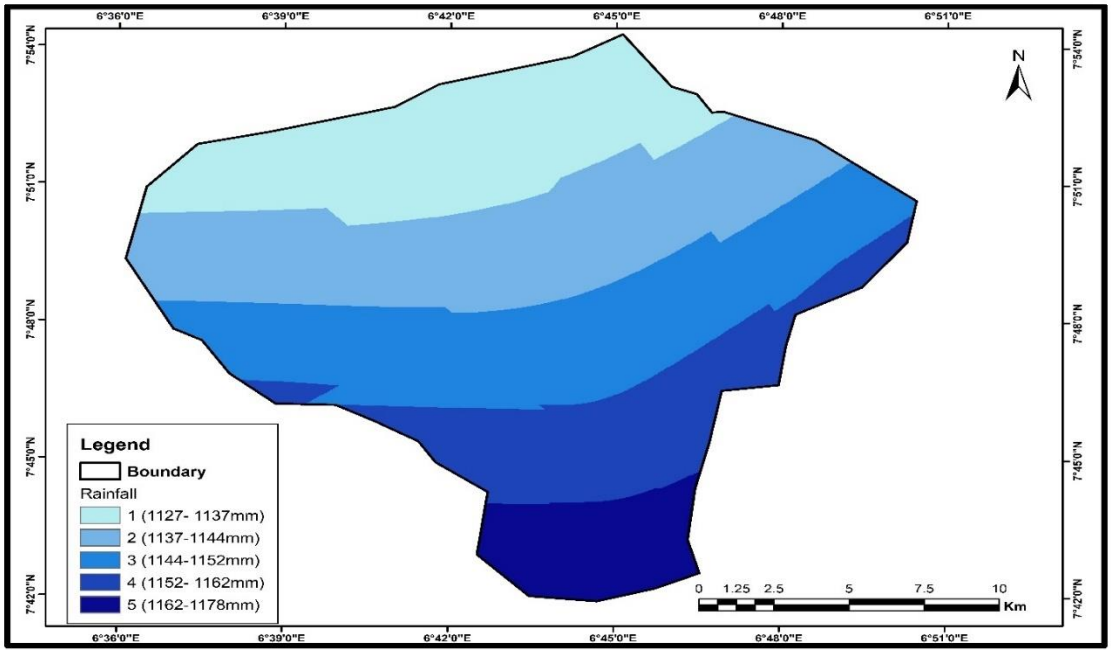


Figure 4.4: Reclassified Rainfall of Lokoja Metropolis.
Source: Author's Analysis, 2024

Table 4.2 presents the results for various rainfall classes.

Rainfall (mm)	Weightage	Potential	%
1127-1137	1	Very Low	0.06
1137-1144	2	Low	0.10
1144-1152	3	Moderate	0.16
1152-1162	4	High	0.26
1162-1178	5	Very High	0.42

4.1.5 Geology

The geology of the study area is made up of six major rock types which are the unconsolidated alluvium that allows extremely very high permeability and groundwater flow which forms the bedrock of the study area covering 89.53 Km² (26.85%), sand and siltstone with high sedimentary rocks with high permeability, allowing significant groundwater flow covering 86.05km² (25.81%), migmatite with moderate and partially melted rocks with variable permeability, allowing groundwater flow covering 102.56km² (30.76%) granite and Charnock granite with low coarse grained granites with low permeability, limiting groundwater flow covering 1.89km²(0.56%), granite migmatite and gneiss with low metamorphic rocks and low permeability, limiting groundwater flow covering 19.43km ² (5.82%) and Amphibole Schist which forms the remainder of the study area made of metamorphic rocks with extremely low permeability, unfavourable for groundwater flow covering 33.92km² (10.17%). (See Figure 4.15 and Figure 4.16). It can be seen that alluvium has the most weight of 51% and is more likely to be water bearing when compared to the other rock types. Consequently, the rock types present were classified into very low, low, moderate, high and very high based on their groundwater bearing potential.
As evident in Table 4.10, it can be observed that Alluvium exhibits a notably very high groundwater potential, while Sandstone and Siltstone display a high-water potential. Migmatite and Granite and Charnock Rock present moderate groundwater potential, Granite Migmatite and Granite Gneiss

present low groundwater potentials. In contrast, Amphibole Schist demonstrate very low groundwater potentials.

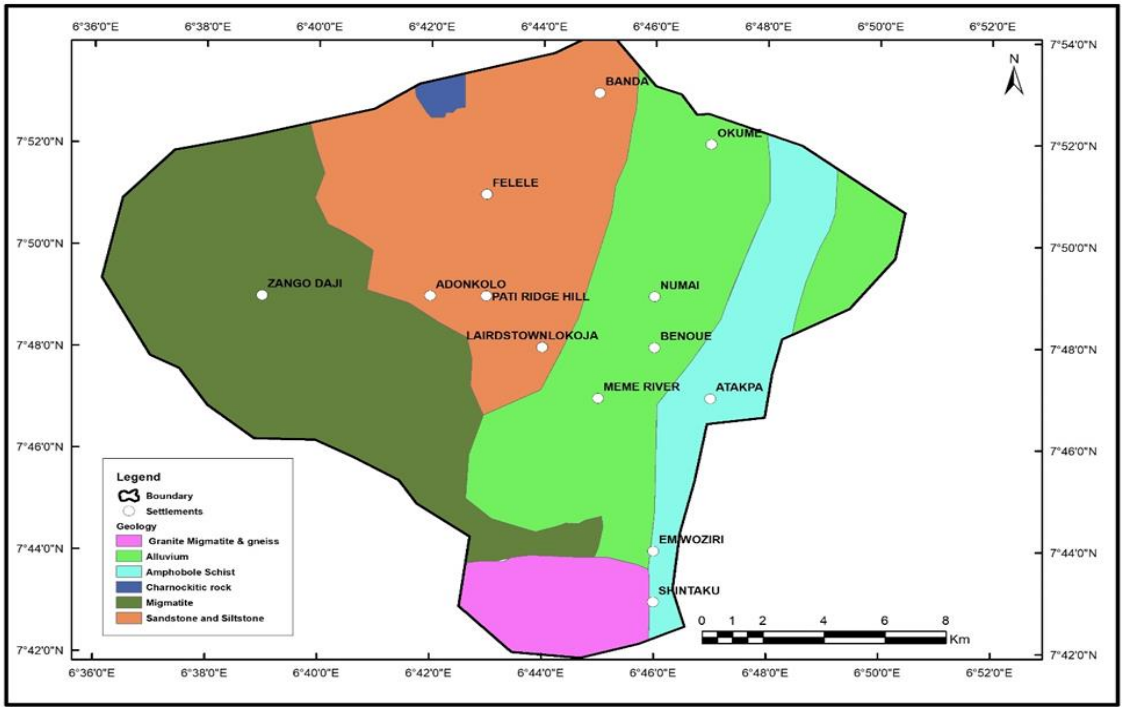


Figure 4.15: Geology of Lokoja Metropolis.
Source: NGSA, 2014

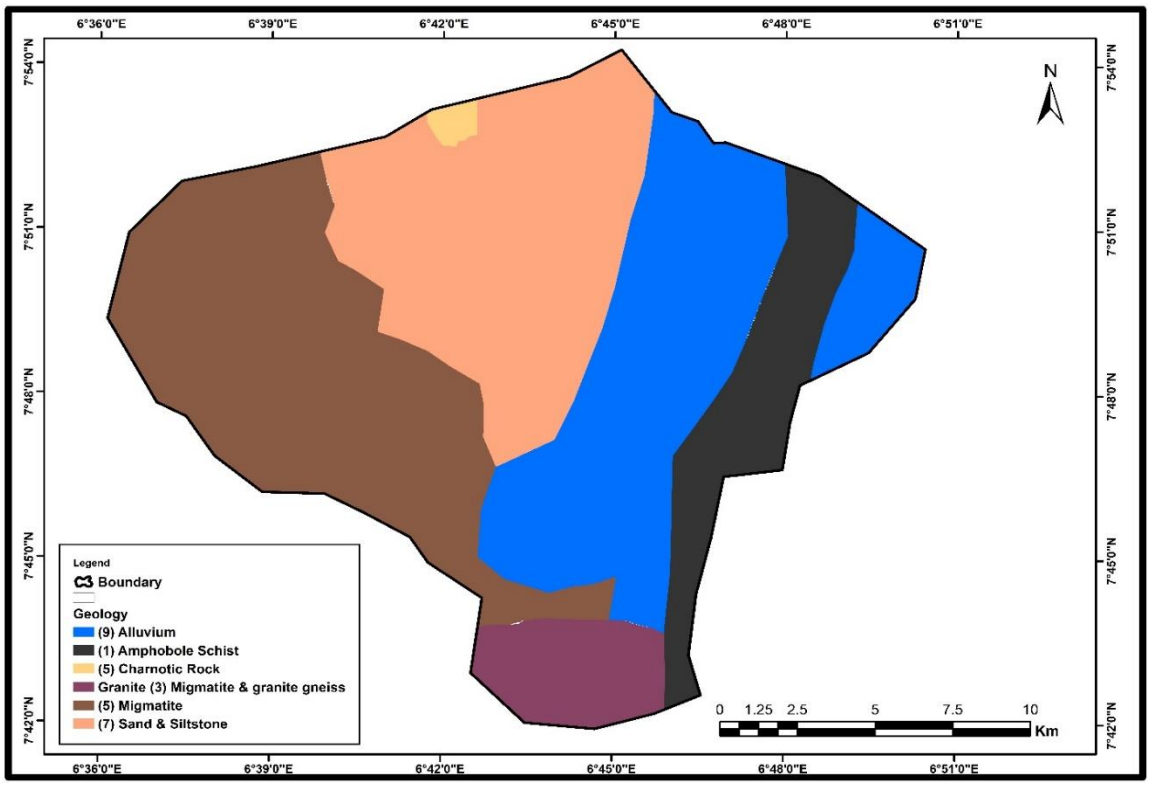


Figure 4.16: Reclassified Geology of Lokoja Metropolis.
Source: Author's Analysis, 2024

The result of the pairwise comparison and weighting of the types of geology present in the study area is presented in Table 4.10.

Table 4.10: Groundwater potential Based on Geology in Lokoja Metropolis

Geology	Weightage	Potential	%
Alluvium	9	Very High	0.51
Sand& Siltstone	7	High	0.17
Migmatite	5	Moderate	0.10
Granite& Charnock	5	Low	0.10
Granite Migmatite & Gneiss	3	Low	0.07
Amphibole Schist	1	Very Low	0.05

Consistency Ratio=0.06
Source: Author's Analysis, 2024

4.2 Results on relationship between existing Borehole Yields and the Groundwater Potential Zones

The study provides borehole points, yields, and Groundwater Potential Map (GWPM). The coordinates of 42 boreholes were entered into the ArcGIS environment and superimposed on the GWPM, as detailed in table 4.13. About 2.8% exhibited very high discharge rates, 36.1% had high discharge rate, 19.4% had moderate discharge rate, 16.7%, displayed low discharge rate, and very low discharge rate displayed 2.8% and the remaining 22.2% fell on different groundwater classes. The analysis of borehole yields in Lokoja metropolis reveals a significant correlation with the Groundwater Potential Map (GWPM). However, a notable 22.2% of the boreholes exhibit yields that differ from the predicted areas, indicating local variations in groundwater potential that may be influenced by factors such as geology, topography, or hydrological conditions. These findings underscore the utility of the GWPM as a valuable tool for decision-making in water resource management and infrastructure development, while also highlighting the need for refined mapping and site-specific assessments to enhance its accuracy and reliability. This outcome is a bit similar with the findings of Adaviruku et al. (2023), where 81.25% of boreholes in Okene aligned with their corresponding groundwater potential zones. Table 4.13 show the classification of borehole yield and groundwater potential of the study area. (See Figure 4.19) showing GWPZ map with the borehole positions overlain.

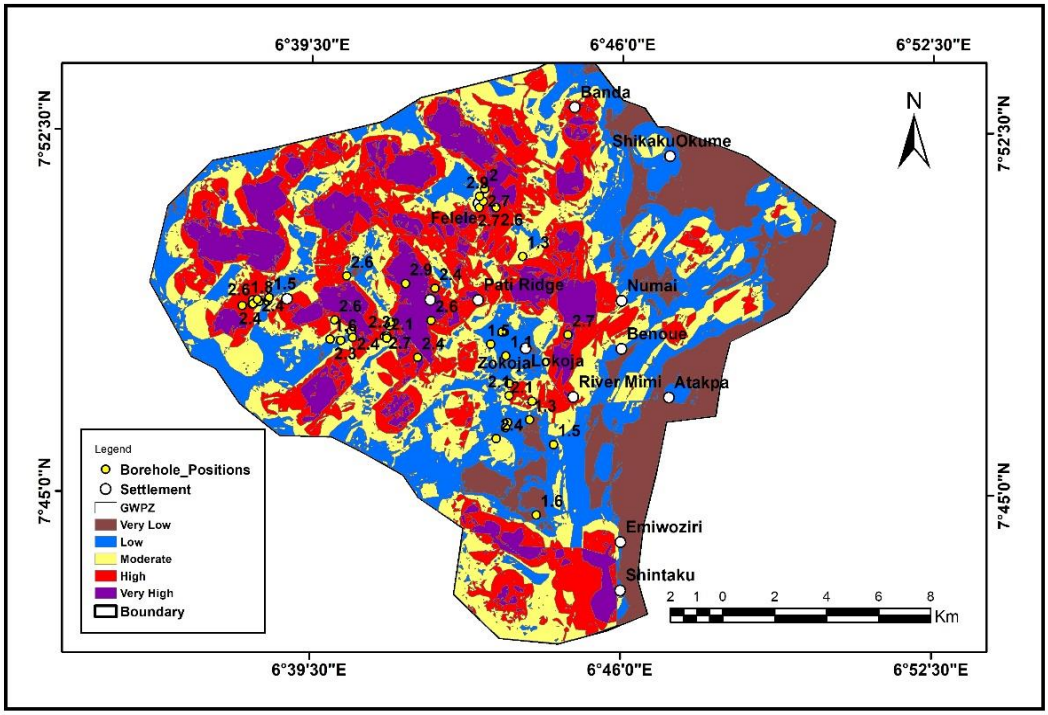


Figure 4.19: Groundwater Potentials Zone of Lokoja Metropolis Showing Borehole Positions.
Source: Author's Analysis, 2024.

Refer to Table 4.13 below for detailed borehole yield data, classifications of groundwater potential zones, and their corresponding remarks.

Table 4.13: Borehole Yields and Groundwater Potential zones remarks
Borehole Yields and Groundwater Potential Map

S/N	X (m)	Y(m)	Expected yield description from map	Actual yield from Drilled Borehole	Actual Borehole yield Description	Remarks
1	248247.732	868245.626	High	2.7	High	Coincide
2	248898.644	868242.087	High	2.6	High	Coincide
3	248403.451	868477.121	High	2.7	High	Coincide
4	243147.038	865629.317	High	2.6	High	Coincide
5	245407.352	865340.253	Very High	2.9	Very High	Coincide
6	246542.813	865157.013	Moderate	2.4	Moderate	Coincide
7	239787.264	864652.239	High	2.5	High	Coincide
8	239510.859	864554.208	High	2.6	High	Coincide
9	239522.824	864720.109	High	2.5	High	Coincide
10	239124.36	864501.055	High	2.4	High	Coincide
11	239544.085	864576.151	High	2.6	High	Coincide
12	239710.523	864741.185	Moderate	2.4	Moderate	Coincide

13	240107.37	864672.575	Low	1.8	Low	Coincide
14	240163.283	864805.036	Low	1.5	Low	Coincide
15	246392.674	863929.726	High	2.6	High	Coincide
16	242685.348	863950.104	Moderate	2.3	Moderate	Coincide
17	244791.643	863728.271	Moderate	2.5	High	Not Coincide
18	244836.567	863871.859	Moderate	2.1	Moderate	Coincide
19	243322.988	863526.137	High	2.2	Moderate	Not Coincide
20	242912.715	863163.283	Moderate	2.3	Moderate	Coincide
21	244601.82	863319.941	High	2.7	High	Coincide
22	251652.832	863381.328	Very High	2.7	High	Not Coincide
23	244690.213	863341.583	High	2.3	Moderate	Not Coincide
24	248682.8	863021.113	Low	1.5	Low	Coincide
25	244689.727	863253.073	High	2.1	Moderate	Not Coincide
26	243376.814	863282.427	High	2.4	High	Coincide
27	242504.701	863209.797	Low	1.6	Low	Coincide
28	245877.392	862516.341	High	2.4	High	Coincide
29	249389.45	861059.008	Moderate	2.1	Moderate	Coincide
30	250271.046	860844.067	High	2.1	Moderate	Not Coincide
31	250178.983	860136.481	Very Low	1.3	Very Low	Coincide
32	249261.477	859831.614	Low	1.1	Very Low	Not Coincide
33	248895.082	859413.157	Moderate	2.4	Moderate	Coincide
34	251100.844	859191.145	Low	1.5	Low	Coincide
35	250435.481	856506.212	Low	1.6	Low	Coincide
36	248461.202	868952.554	High	2	Moderate	Not Coincide

(Source: Author's Analysis, 2024)

Table 4.14: Classification of Borehole Yield

Groundwater potential	Discharge rate L/s	No of Actual Drilled Boreholes	No of Drilled Boreholes That Coincide with Expected Yield Map
Very High	2.87- 3.90	2	1
High	2.45- 2.87	18	13
Moderate	2.04- 2.45	8	7
Low	1.59- 2.04	7	6
Very Low	0.85- 1.59	1	1

(Source: Author's Analysis, 2024)

Overall, the results showed that the very low potential locations had extremely low discharge rate (<1.5 l/s) and the very high potential areas had substantial discharge rate (>2.87 l/s). The areas in between these extremes have intermediate values. Borehole locations with discharge rate of 0.85 <1.59 l/s are found in the very low zones, 1.59 < 2.04 l/s are found in the low zones, 2.04 < 2.45 l/s are found in the moderate zones, 2.45 < 2.87 l/s are found in the high zones, and 2.87 < 3.90 l/s are found in the very high zones of groundwater potential. According to Appendix 2, the majority of the research area's suitable groundwater areas are located in the southern, western, and central regions. In contrast, there is decreased chance of groundwater incidence in the northeastern to southeast regions of the research area.

Table 4.15 summarizes the results which examined the relationship between borehole yields and groundwater potential zones. The analysis showed a strong positive correlation indicating that

higher groundwater potential zones are associated with increased borehole yields. This suggests groundwater potential zones are reliable predictors of borehole yields, important for water resource management.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study highlights significant spatial variability in groundwater potential within the study area, closely aligning with variations in geology, lineament density, rainfall, elevation, slope, drainage density, and land use/cover. It was found out that geology, lineament density and rainfall are the three most influencing factors in the area. The areas with the most promising groundwater potential were characterized by low slope and high lineament density. Moreover, zones with low to very low groundwater potential tend to be located far away from regions with high concentrations of lineaments, which could be indicative of groundwater aquifers. It therefore concluded that in a basement complex like Lokoja metropolis, geology, lineament density and rainfall are the most prominent groundwater potential influencing factors.

Thus, it was concluded from this study that although groundwater is available everywhere, the potentiality varies over space owing to the role played by the different factors influencing groundwater potentials as geology plays a significant role in the possible occurrence of groundwater in the subsurface. The validation carried out on the proposed model reveals a 78% prediction accuracy.

5.2 Recommendations

In relation to the findings obtained from the research work and conclusion reached, the following recommendations are forwarded;

a. The relevant stakeholders may wish to prioritize very high and moderate groundwater zones for borehole installations, particularly in the northern, western, and southern regions, to ensure sustainable water supplies.
b. The relevant stakeholders may wish to conduct detailed assessments in areas where actual borehole yields differ from predictions to understand local geological or hydrological factors affecting groundwater in those areas.
c. The relevant stakeholders could develop strategies that account for spatial variations in groundwater potential, by promoting efficient water use and conservation practices in all zones in the study area.
d. The relevant stakeholders may wish to establish a groundwater monitoring network to regularly track the quantity and quality of groundwater, identifying changes due to climate or human activities.
e. The relevant stakeholders would need to continue gathering data on rainfall, soil types, and land use to refine assessments of groundwater potential, using advanced remote sensing for improved accuracy.
f. In very low potential zones, the relevant stakeholders would need to consider rainwater harvesting and surface water use to meet local water demands without stressing groundwater supplies.

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