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Determination of Groundwater Producing Zones in Kaduna Metropolis, Kaduna State, Nigeria

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Abstract

This study investigated groundwater producing zones in Kaduna metropolis using remote sensing and GIS techniques. The data used are Landsat 8 (OLI) 30m, Aster (30m), geologic, soil and topographic maps of the study area to generate the land use-land cover, slope, geologic rock types, soil textures and drainage density. All the attributes of each factor were rated and classified according to their importance to groundwater occurrence. Each factor was also weighted according to their importance to groundwater by using the Modified DRASTIC Model for simulation and integration. The weighted overlay technique was used in ArcGIS 10.0 to determine groundwater-producing zones. Groundwater potential map generated were classified into four classes that describe the productivity of each cell in the study area for groundwater exploration. These classes are poor, moderate, good and very good. It was found that about 30% of the area was classified as very good and found to be concentrated in the central part of the study area. About 26% and 23% of the area were classified as good and moderate areas respectively. The rest of the study area (21%) was classified as poor and found in northeast and southwest part of the study area. This result was verified against existing well data and field observations to validate the accuracy of the model. Geology and geomorphology were the most effective among the six factors as the major chief determinants of groundwater accumulation. The study recommends that other factors that affect groundwater accumulation should be incorporated in future research.

Keywords: *Groundwater, Drastic Model, GIS, Hydrogeology, Sustainable Development Goals*

Introduction

Surface water resources are inadequate to meet all the water requirements of the global population; hence there is an increased demand for groundwater resources (Jyoti and Tiwari, 2011). Groundwater is one of the major resources that is important for sustainable growth and development, and has a key role to play in the SDGs either directly in terms of food, hygiene and health, protection and restoration of ecosystems and biodiversity, or indirectly, for the reduction of poverty and inequalities, contribution to education and gender equality

(International Groundwater for Resource Assessment Centre IGRAC, 2022). The United Nations University Institute for Water, Environment and Health UNU-INWEH (2018), in their study state that groundwater had secondary linkages with SDG targets and of the 126 SDG targets that were analysed, 53 targets (42%) were found to have implications for groundwater with SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production) and SDG 13 (climate action) as having the closest links with groundwater. They equally noted that SDGs without direct links to groundwater still have implications for groundwater; for example, access to groundwater has implications for peace (SDG 16) and groundwater discharge to coastal areas has implications for marine water quality (SDG 14). Groundwater is the primary source of domestic, agricultural, and industrial use in many regions of the world. It is a more preferred resource due to its less susceptible contamination than surface water.

In Nigeria, the population has been increasing at an alarming rate while water supply has not been able to follow the same trend. Water supply coverage of Nigeria has remained at 57% for a very long time (Olasehinde, 2010). This percentage can be greatly improved by the conjunctive use of surface and groundwater resources. The state of groundwater is subject to resource-specific characteristics, (UNU-INWEH, 2018) human activity in the catchment area and socio-economic processes that may transcend the catchment level and even have international implications. Human impact on groundwater is thus the resultant of complex processes on various levels. Groundwat an integrated GIS and remote sensing study can provide the appropriate platform for the convergent analysis of large volumes of data and quite decision-making techniques for groundwater exploration which not only provides information on inaccessible areas but saves time and money as well. Thus, remote sensing and GIS are being increasingly used for the identification of groundwater potential zones as well as groundwater recharge and discharge zones.

Kaduna metropolis is the largest city and the capital of Kaduna state. The demand for water was fast outpacing its availability for consumption (Udoh and Etim, 2007). In a bid to ameliorate the condition, it has become imperative to carry out a groundwater assessment of Kaduna metropolis to determine areas of groundwater potentials. Consequently, the essence of this research is to apply geospatial techniques towards identifying areas of groundwater productivity for fast extraction of information as well as promising areas for groundwater exploration. As a result, the research specifically determined the hydrogeological set-up (groundwater indicators) within study area; assigned priority scales for each hydrogeological

set-up using the DRASTIC Ratings; generated groundwater productivity map using DRASTIC model; and validated the groundwater productivity map using the yield data.

Materials and Methods

The methodology applied in this research is DRASTIC Model which was founded by the United States Environmental Protection Agency (USEPA) as a standardized approach for evaluating pollution of groundwater potentials (Aller *et al*., 1987). DRASTIC is an acronym standing for Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and hydraulic Conductivity. Each of the components of the DRASTIC model is explained as: D=Depth of water, R=Net recharge, A=Aquifer media, S=Soil media, T=Topography, I= Impact vadose zone, H=Hydraulic conductivity. The DRASTIC model contains three significant parts namely: The weight, ranges and ratings.

The equation for DRASTIC index is

$$GPP=D_rD_w+ R_rR_w+ A_rA_w+ S_rS_w+ T_rT_w+ I_rI_w+ C_rC_w \quad \text{Eq 1}$$

Where r= Ratings, w= weight

GPP= Groundwater Pollution Potentials

The study area is Kaduna metropolis, located between Lat. N$10^0$23’ and $10^0$43’N and Long. $7^0$17’ and $7^0$37’E (Figure 1). The population of the city has experienced rapid growth from about 169,125 in 1967 to a projected figure of 1,371,805 in 2009 from the 2006 population census

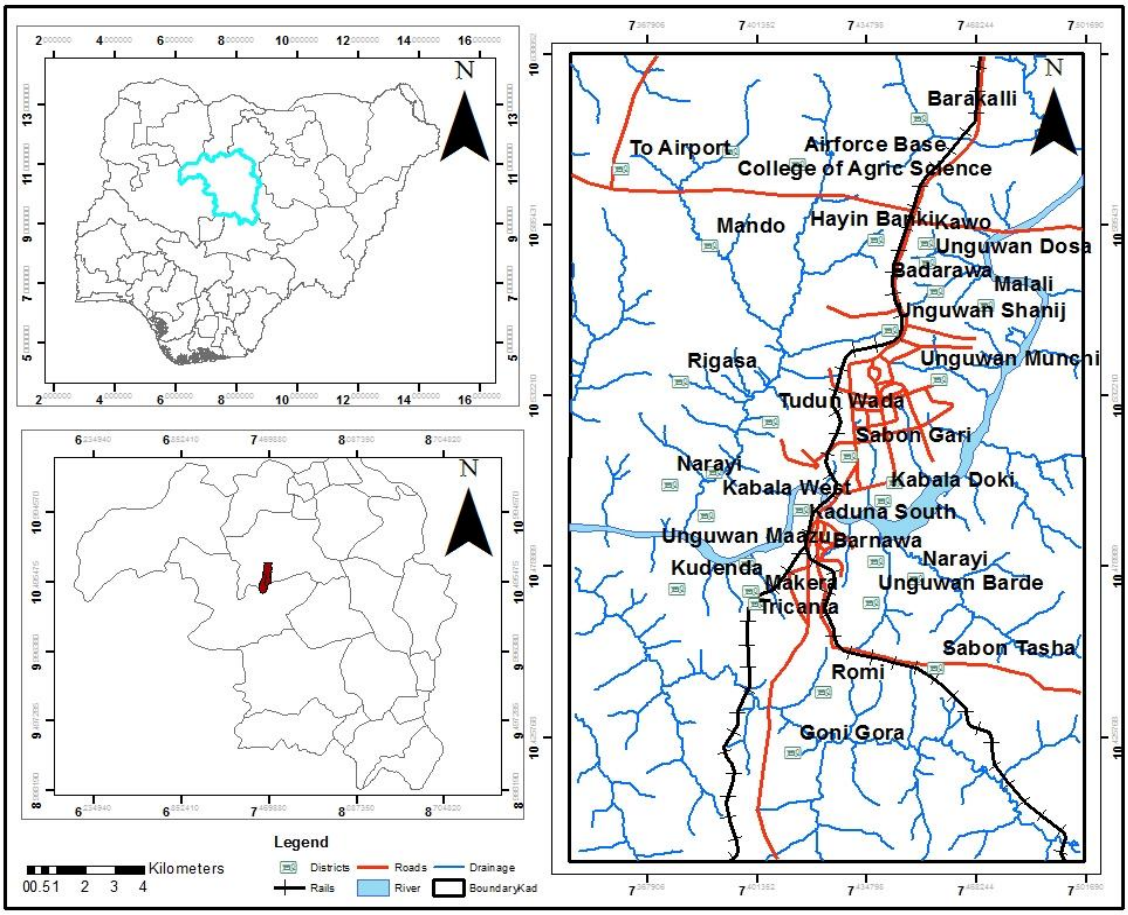


Figure 1: Kaduna Metropolis
Source: Authors' Analysis, 2022

Data Types and Sources

The data types and sources are as displayed in Table 1

Table 1: Data type and sources

Data	Source	Date	Relevance
Topographic map	Office of the surveyor general (OSGOF), Abuja	1966	Drainage
Soil map	State ministry of Agriculture (Kaduna State)	2020	Soil
Geologic map	Nigerian geological Survey Agency	2008	Geologic (rock type)
ASTER data (30m)	www.glcf.com	2020	Slope
Landsat 8 (OLI) (30m)	USGF	2020	Land use/cover

Source: Authors' Compilation, 2022

Global positioning System (GPS) receiver (Hand Held) was used for point and route data collection in the field.

Procedure

Image Analysis

The Advance Space-borne Thermal Emission and Reflection imagery (ASTER) data of 30m resolution and the Landsat 8 (OLI) (30m resolution), of path (189/53), year 2020 with 7 bands and orthorectified were both sub-mapped to Kaduna metropolis. The land use-cover map was prepared with the aid of satellite images. The procedure in extracting basic information from digital remote sensing imagery involved digital image composition, manual interpretation and classification of various categories after conducting ground truthing.

Pre-Processing: The Landsat 8 (OLI) referencing the Minna Datum was used for image processing for the study area and mapping of some required set.

*Image Transformation***:** Image transformation was employed to differentiate the various brightness values which may cause conflicting appearances as a result of identical surfaces appearing on the image due to slope, aspect, topography, shadows as well as sunlight illumination angle and intensity. Vegetation discrimination was done using false colour composite in RGB order of bands 753 of Landsat 8 (OLI).

Image Classification: Image classification was done through the application of statistically based decision rule for the determination of the land use/cover type for each pixel in the image. Unsupervised classification was performed in order to have a general idea of the area which was followed by supervised classification for the final land use/cover mapping.

GIS Analysis

The hydrogeological resources of the study area were mapped and inputted into a GIS environment for proper analysis by creating a geo-database for proper data management of all dataset involved in the study: land use/cover, geology, soil, slope and geomorphology from ASTER, drainage density, and ground truthing so as to aid modelling for groundwater producing zones. All datasets were rasterized using uniform cell.

Slope steepness

Slope was prepared from DEM with 30 m resolution using a spatial analysis tool in ArcGIS 10.3. The slope amount was obtained in degrees from the contours that were generated from the sub-mapped ASTER data of Kaduna metropolis. In the GIS environment, the contours were

subjected to spatial analysis using the spatial analyst module in ArcGIS 10.3 to generate the slope. The slope amount derived was further classified appropriately.

Land use and cover

The land use/cover of Kaduna metropolis was obtained from Landsat 8 imagery by subjecting it to unsupervised classification using ENVI 4.5, which gave a general idea of the land use/cover classes of the area. Bands 7, 5 and 3 were combined to obtain a colour composite that was used for the unsupervised classification. Information obtained from ground truthing was used to reaffirm land use/cover class before subjecting the imagery to supervised classification. The land use/cover of the study area was classified based on ground truthing.

Soil Texture

Soil type plays a vital role in controlling the infiltration rate of precipitated water and water-holding capacity of the area. Consequently, it could be considered as one of the important factors for the delineation of groundwater potential zones. The soil map of Kaduna metropolis produced by the State Ministry of Kaduna State scale of 1:40,000 was scanned and imported into ArcGIS 10.3 environment where it was georeferenced based on the map projection of GCS, Minna Datum.

Geology.

The geologic map of Kaduna Metropolis produced by the Nigerian Geological Survey Agency Sheet 32, and scale of 1:250,000 was scanned and imported into ArcGIS environment where it was georeferenced based on the map projection of GCS, Minna Datum. Each rock type was digitized. Field study was also conducted to verify the information obtained.

Drainage

Drainage density is one of the important indicators of groundwater recharge and groundwater occurrence. The topographic map of Kaduna Metropolis obtained from Sheet 144 (Kakuri) and Sheet 123 (Kaduna), and scale 1:100,000, First edition was scanned and imported into ArcGIS 10.3 environment where it was georeferenced based on the map projection GCS, Minna Datum: Both maps was mosaic and the study area was clipped form the maps. The river drainages of the study were digitized. Verification was also done using the Landsat imagery, ASTER as well as ground truthing.

A digital elevation model (DEM) with 30m resolution was obtained from Shuttle Radar Topography Mission (SRTM) to derive slope and drainage density map using the ArcGIS tool.

The development of drainage density involves filling sinks, flow direction, flow accumulation, and stream network extraction. Then, the drainage density map was produced using a line density analysis tool. Landsat 8 Operational Land Imager (OLI) satellite image was obtained from the United States Geological Society (USGS) website and used to generate lineament density and LULC maps (https://earthexplorer.usgs.gov/)

Results and Discussion

Determination of Hydrogeological Set-up within the Study Area (Groundwater Indicators)

Topography

The slope classes obtained in the study area had values (degrees) which include (0- 1.41.), (1.42-2.4), (2.41-3.31), (3.32-4.39), (4.4-5.8) (5.81-8.2) and (8.21-21.1) as shown in figure 2 (a) which was given classes 1-5 and further classified into flat, gentle, moderate, steep and very steep respectively (Table 2) and equally represented in figure 2 (b).

Table 2: Slope classification

Slope Classes	Value in Degree
Flat	0^0-2.31^0
Gentle	2.32^0-4.01^0
Moderate	4.02^0-6.48^0
Steep	6.49^0-11.57^0
Very Steep	11.58^0-39.34^0

Source: Author's Analysis, 2022

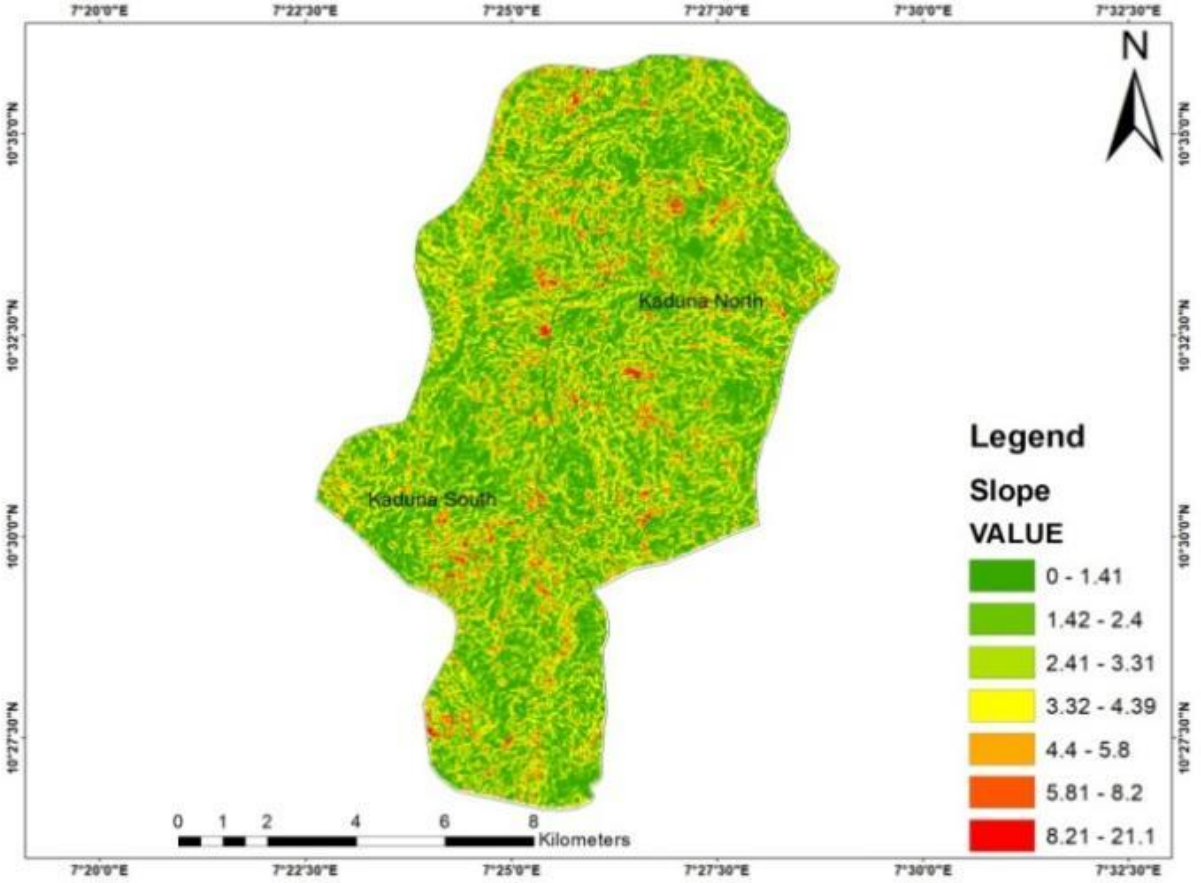


Figure 2(a): Slope Pattern of Kaduna Metropolis.

Source: Author's Analysis, 2022

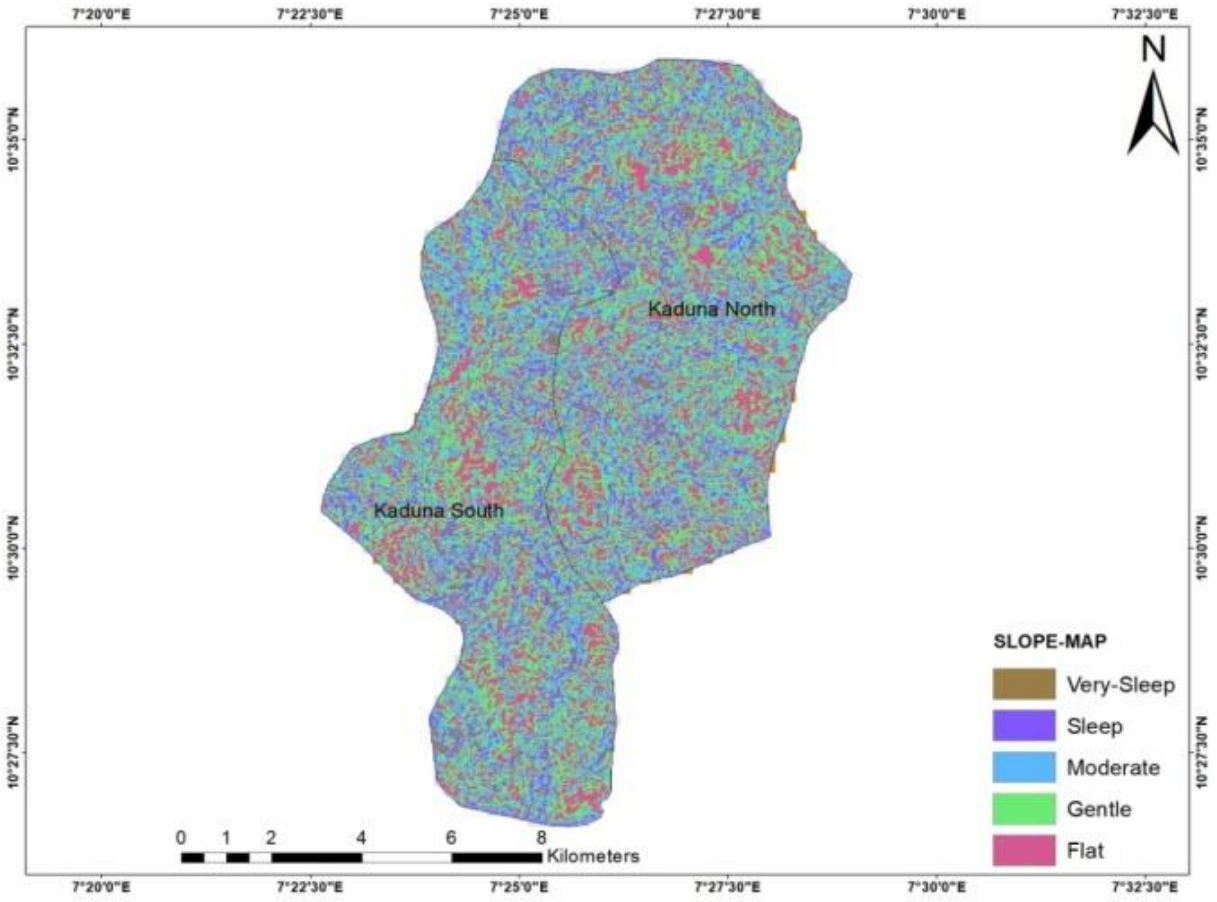


Figure 2 (b) Classified Slope Pattern of Kaduna Metropolis

Source: Author's Analysis, 2022

Land use-Land cover

One of the parameters that influenced the occurrence of sub-surface groundwater is the present condition of land cover and land use of the area. The effect of land use and Land cover is manifested either by reducing runoff and facilitating, or by trapping water on their leaf. Water droplets trapped in this way go down to recharge groundwater. Land use and Land cover may also affect groundwater negatively by evapo-transpiration, assuming interception to be constant.

The Land use and Land cover of the area provides important indications of the extent of groundwater requirement and utilization. The synoptic viewing through remote sensing has provided the multi-spectral data, which has been utilized for classifying the land use and land cover. The land use-cover type in the study area was classified into five (5) and their number of pixels and corresponding areas on ground by each land cover type is shown in figure 3.

The land use-land cover classes (table 3) are the built-up land (49.805%), farm land (3.861%), bare land (24.080%), vegetation (21.644%), water body (0.610%). The area with water body is good for groundwater recharge and bare land is poor for it (Chowdary et al., 2009).

Table 3: Land use-Land cover classification

Land use-land cover	Trained Pixels	Classified Pixels	Area (Hectares)	Area (%)
Water body	68	3,254	292.8600	0.610
Settlement	2880	265,616	23,905.4400	49.805
Vegetation	254	115,430	10,388.7000	21.644
Bare-surface	175	128,423	11,558.0700	24.080
Farm land	398	20,591	1,853.1900	3.861

Source: Author's Analysis, 2022

From the confusion matrix generated by the GIS after selecting 185 checkpoints on the field to validate the accuracy of data used for 2022 LULC classification, the indices for errors of omission and commission were calculated using Anderson et al., (1976) method. The results are presented in table 4.

Table 4: Statistics for Confusion Matrix

Variable	Percentage
Average	10.30
Average commission error (Confusion)	8.22
Average user accuracy	89.70
Average producer accuracy	91.78
Overall Map accuracy	88.11
Tested overall accuracy	85.42

Source: Author's Analysis, 2022

From table 4, the overall map accuracy was 88.15% with the average omission and commission errors being 10.30% and 8.22% respectively. The average user accuracy and average producer accuracy were 89.7% and 91.78% respectively. The implication of this statistics is that the overall map accuracy of 88.11% was adequate for the research considering the fact that Anderson et *al.,* (1976) stipulated 85% as required accuracy minimum for a research of this nature.

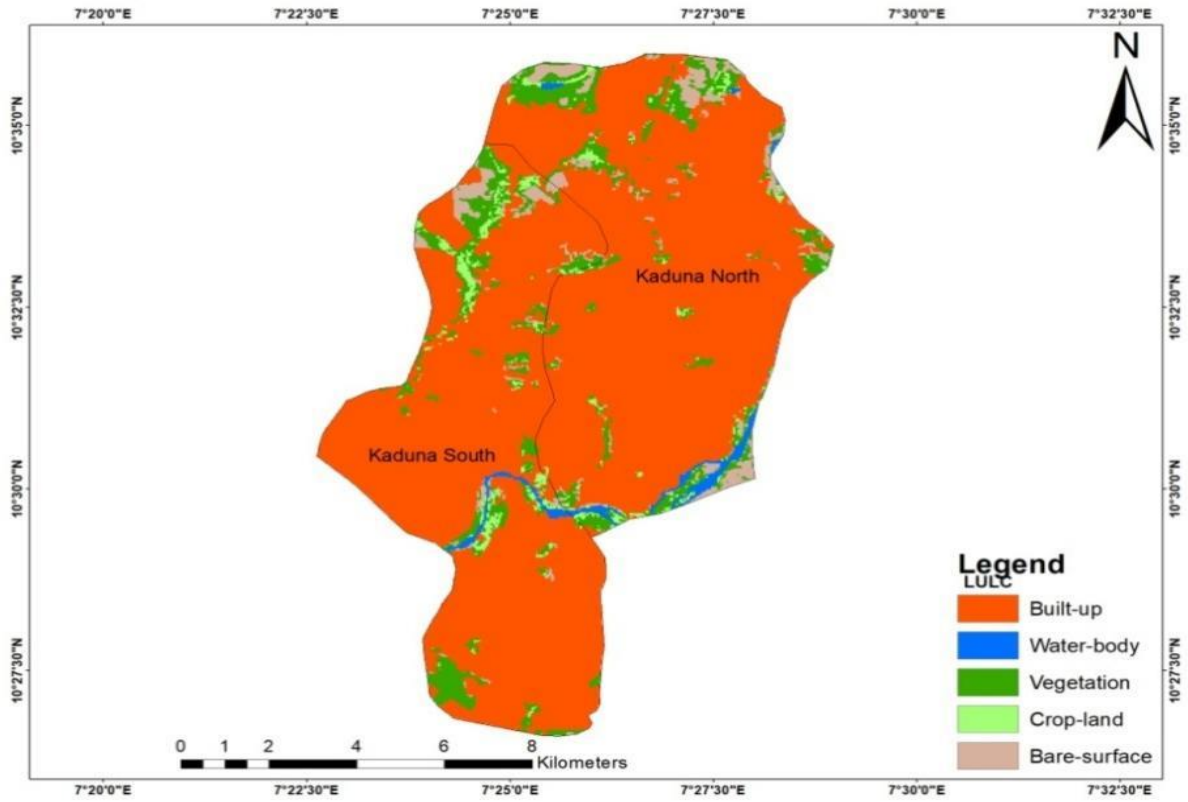


Figure 3: Land use-Land cover of Kaduna Metropolis

Source: Author's Analysis, 2022

Soil Textures

Three soil types found in the study area are Sandune, Sandy clay, Sandy clay loam as shown in figure 4. Sandune had a total of 25 percent or more very coarse, coarse, and medium sand, a total of less than 25 percent very coarse and coarse sand, and less than 50 percent fine sand and less than 50 percent very fine sand. They are hip of sand located at the river bank as well as in the river.

Sandy Clay had 35 percent or more clay and 45 percent or more sand and occupied most of the study area. Sandy loam consisted of 30 percent or more very coarse, coarse, and medium sand, but a total of less than 25 percent very coarse and coarse sand and less than 30 percent fine sand and less than 30 percent very fine sand; or a total of 15 percent or less very coarse, coarse, and medium sand, less than 30 percent fine sand and less than 30 percent very fine sand with a total of 40 percent or less fine and very fine sand.

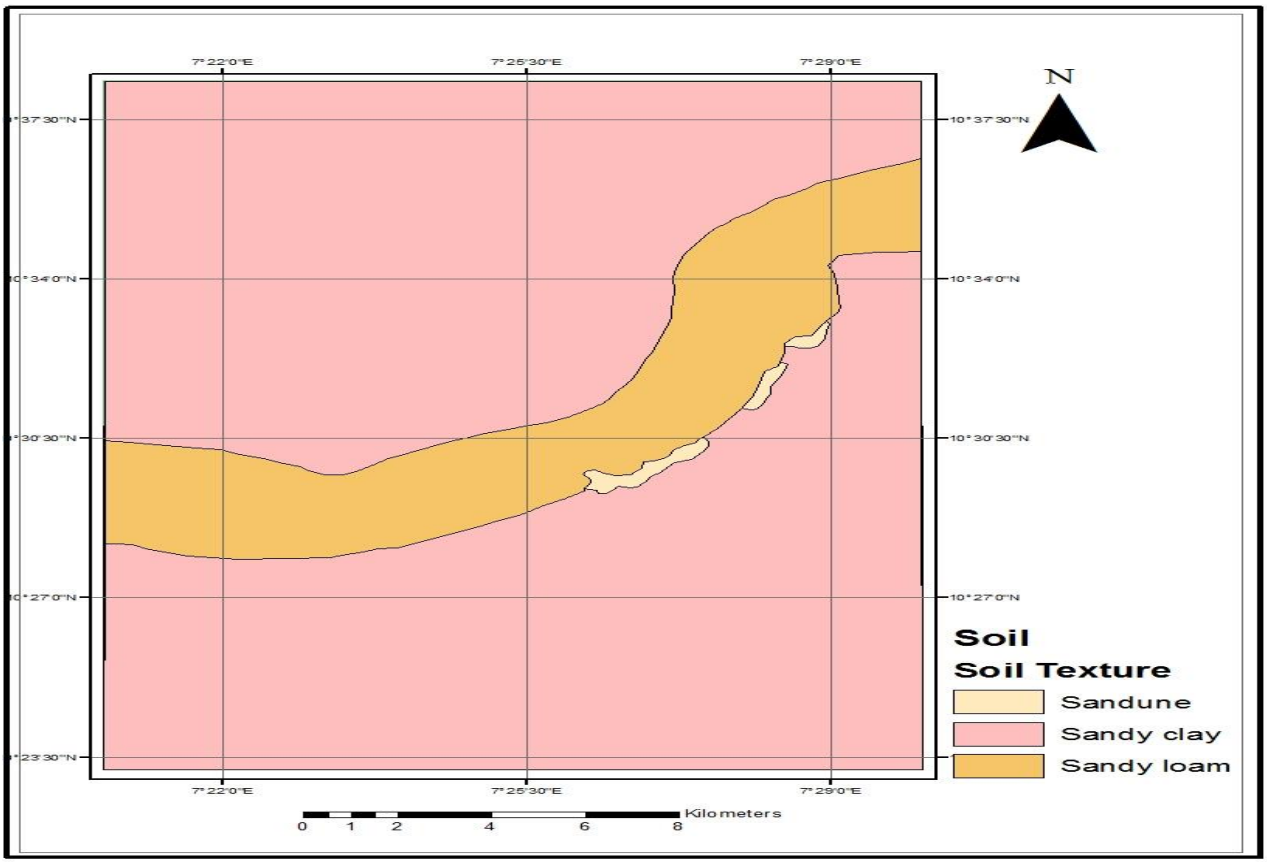


Figure 4: Soil Textures of Kaduna Metropolis

Source: Author's Analysis, 2022

Geology

Geology is a major factor controlling the quality and quantity of groundwater occurrence in a given area. It is represented by the distribution of different rock units characterizing the area under study. The geologic formation of the study area is shown in figure 5.

The major rock types found in the study area are:

i. Biotite and biotite hornblende granodiorite (Pan African Older Granite) consists of about 0.75%

ii. Coarse-grained porphyriic biotite and biotite hornblende gneises (Pan African Older Granite) with about 0.25%

iii. Migmatite (Migmatite Gneises Complex) of 93% total geology of the study area

iv. Schist quartzite pegmatite (Meta-Sedimentary series contain about 6% geologic formation.

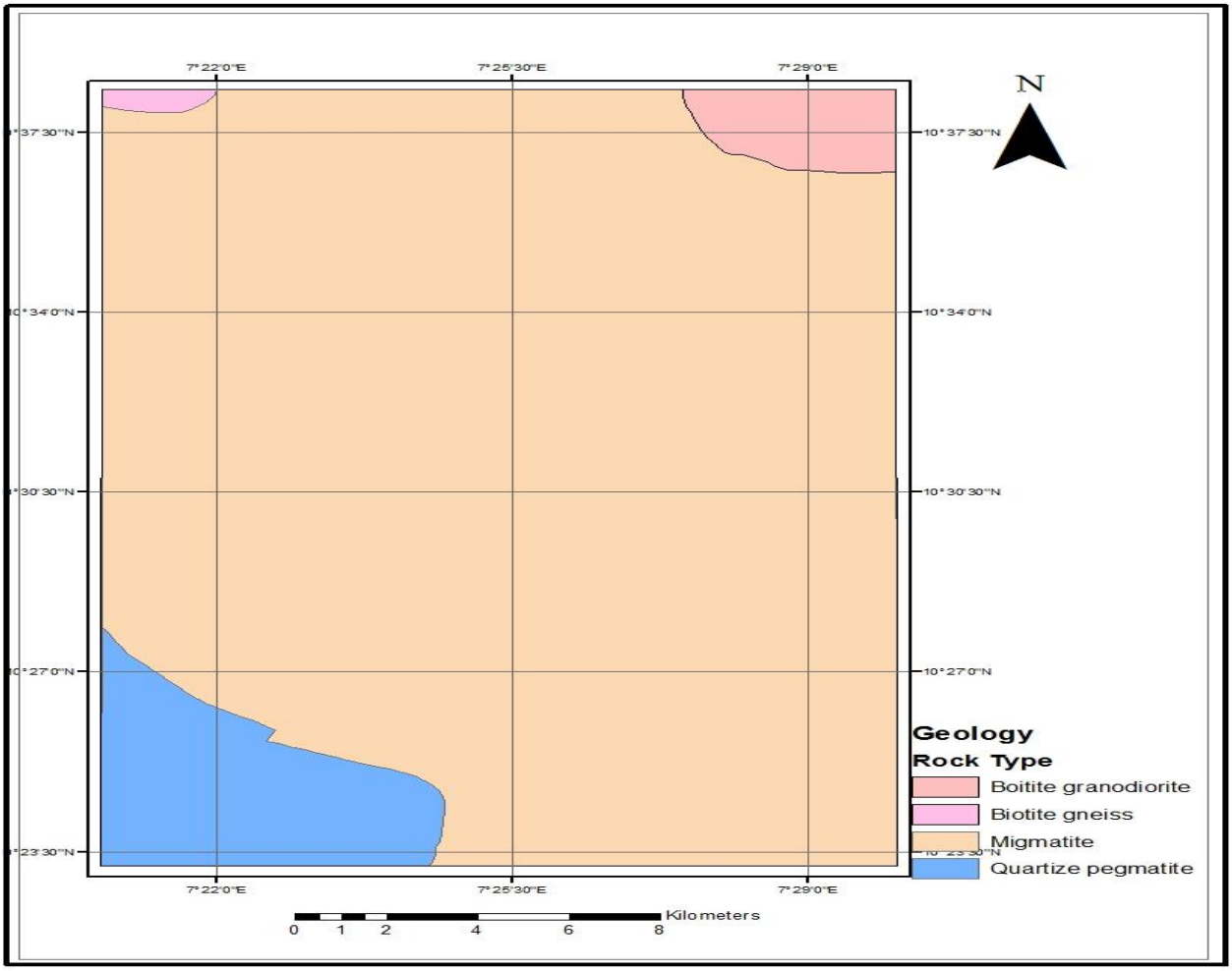


Figure 5: Geologic formation of Kaduna Metropolis

Source: Author's Analysis, 2022

Drainage

Drainage map gives an idea about the permeability of rocks and also gives an indication of the yield of the basin. In addition, the stream pattern is a reflection of the rate that precipitation infiltrates compared with the surface runoff. The infiltration/runoff relationship is controlled largely by permeability, which is in turn a function of the rock type and fracturing of the underlying rock or surface bedrock (Edet *et al.,* 1998). The major river in the study area flows from the northern part to the south. Dendritic drainage pattern is indicative of the presence of structures that act as conducts or storage for groundwater. The drainage pattern of the study area is shown in Figure 6.

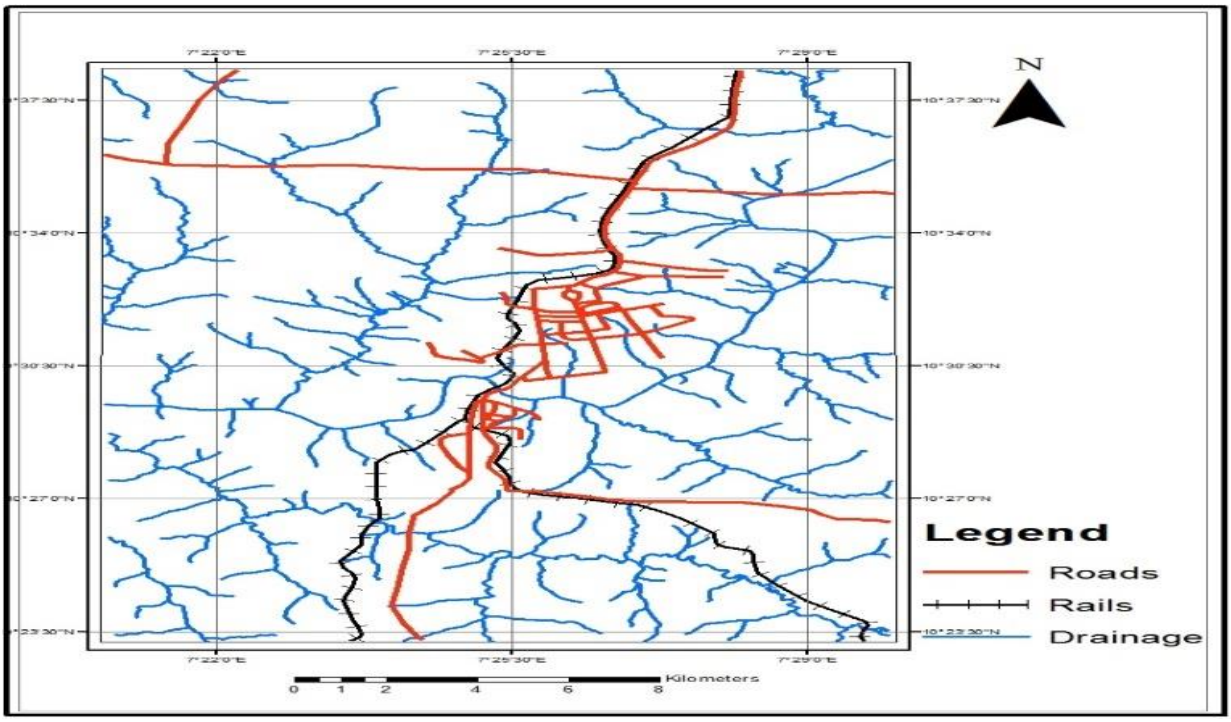


Figure 6: Drainage Pattern of Kaduna Metropolis

Source: Author's Analysis, 2022

Derivation of Priority Scales for Each Hydrogeological Set-up Using the DRASTIC Ratings Techniques.

DRASTIC Rating was applied to the attributes of each factor contained in the drastic model and how the attributes of each factor affected groundwater accumulation and infiltration. The rating is assigned on the basis of steepness (value in degrees) of the terrain as shown in Table 5.

Slope

Table 5: DRASTIC Rating for Slope

Slope Classes	Value in Degree	DRASTIC Ratings
Flat	0^0-2.31^0	10
Gentle	2.32^0-4.01^0	9
Moderate	4.02^0-6.48^0	5
Steep	6.49^0-11.57^0	3
Very Steep	11.58^0-39.34^0	1

Source: Author's Analysis, 2022

Infiltration is inversely related to slope i.e. the flatter the slope then the more the infiltration and hence less runoff (Nag and Anindita, 2011) and therefore groundwater accumulation and infiltration is greater in flat areas than steep areas. Values were assigned using the DRASTIC

ratings to each class of the slope derived based on the fact that the less the slope angle (flat), the better the chances for groundwater accumulation and infiltration.

Land use and Land cover

DRASTIC Ratings was assigned to each class of the land use-Land cover (Table 6) derived based on each characteristic and how it affected groundwater infiltration. A classified land use-Land cover map was obtained as shown in figure 7.

Table 6: DRASTIC Ratings for Land use and Land cover

Land use/cover Classes	DRASTIC Ratings
Water body	5
Settlement	1
Vegetation	10
Bare-Surface	3
Farm land	8

Source: Author's Analysis, 2022

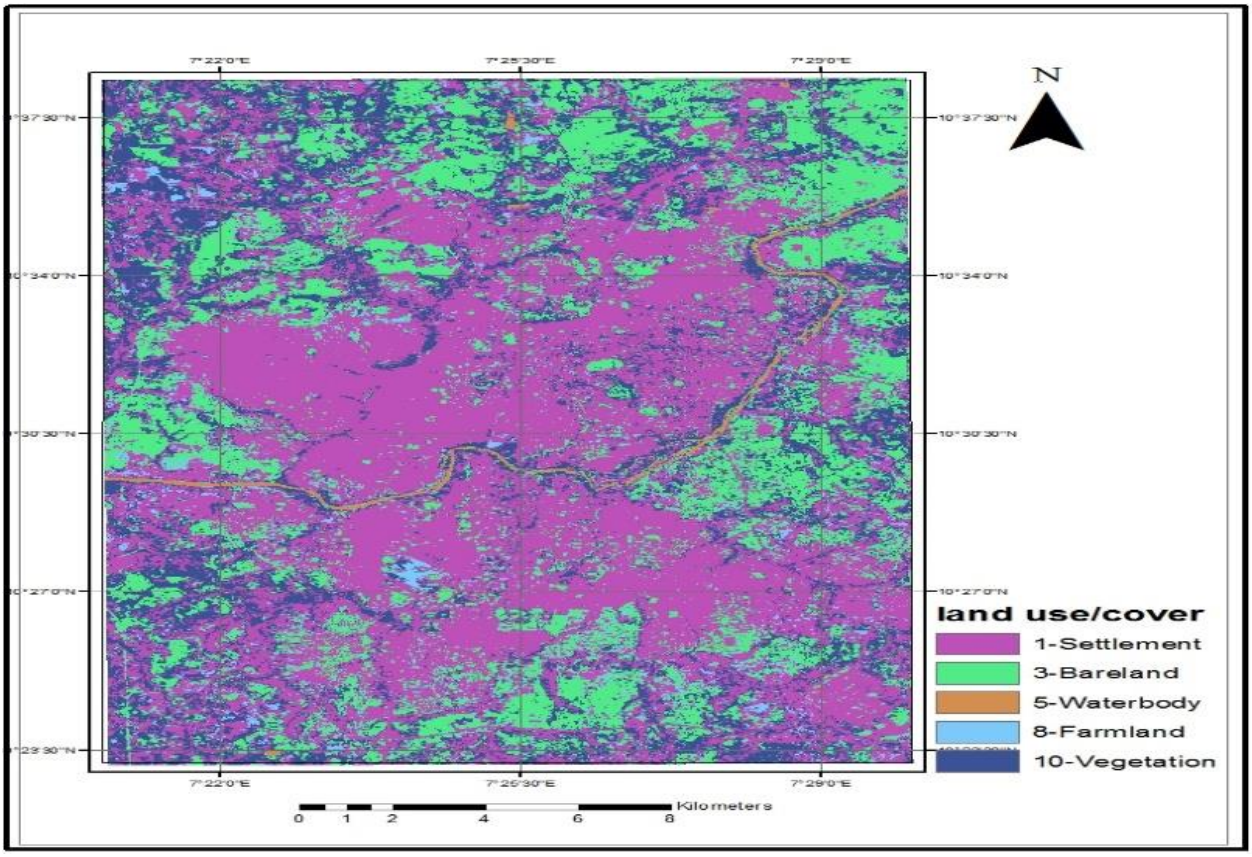


Figure 7: Classified Land use and Land cover of Kaduna Metropolis

Source: Author's Analysis, 2022

Soil Textures

DRASTIC Ratings was assigned to each class of the soil types derived (Table 7) based on each characteristic and how it affected groundwater accumulation. A classified soil map was obtained as shown in Figure 8.

Table 7: DRASTIC Ratings for Soil

Soil Classes	DRASTIC Ratings
Sandune	10
Sandy clay	5
Sandy loam	8

Source: Author's Analysis, 2022

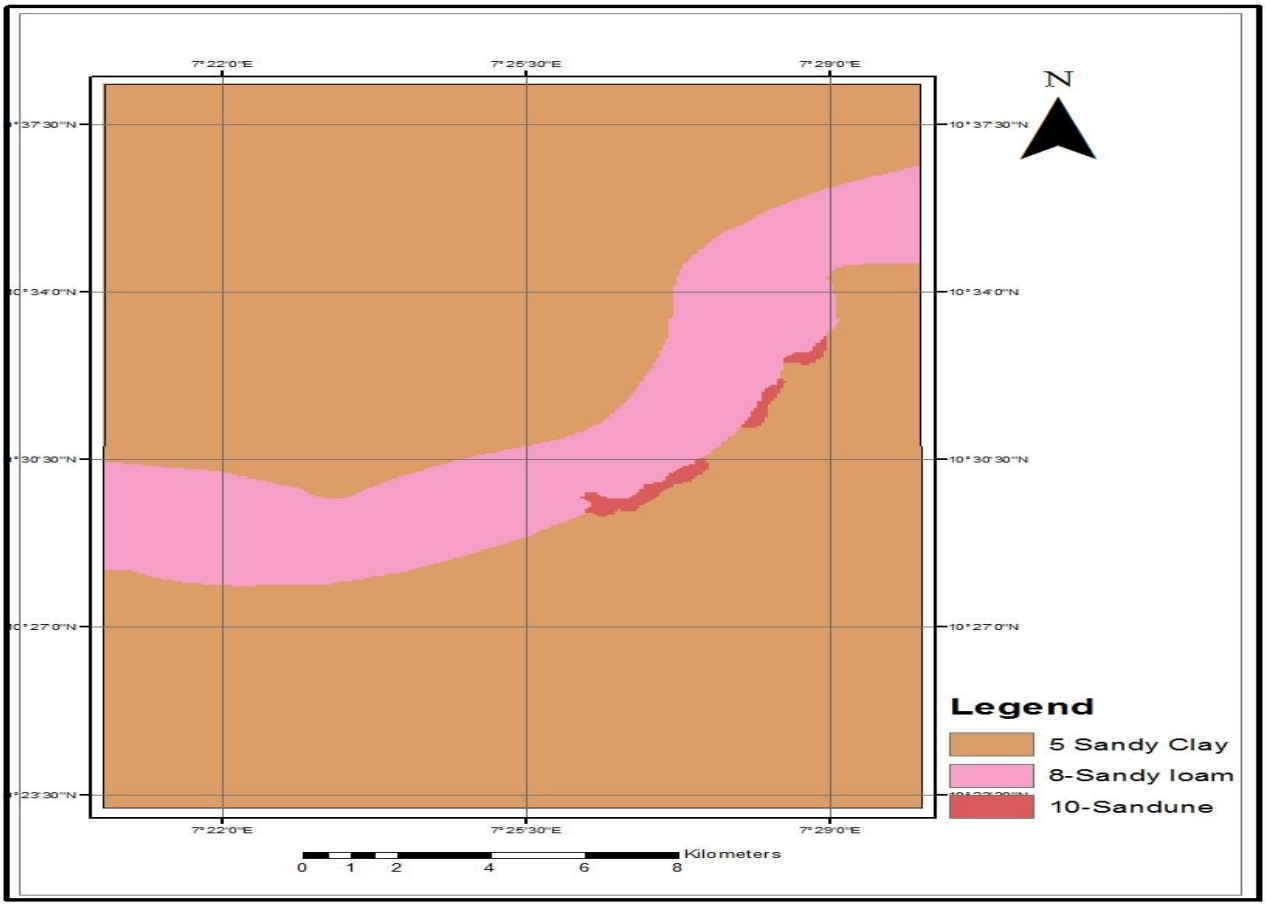


Figure 8: Classified Soil Texture of Kaduna Metropolis

Source: Author's Analysis, 2022

Geology

DRASTIC ratings were assigned to each lithology based on each characteristic and how it affected groundwater accumulation. A classified geological map was obtained as presented in Figure 9.

Table 8: DRASTIC Rating for Rock Types

Rock Type	DRASTIC Ratings
Migmatite	9
Quartzite pegmatite	7
Biotite granodiorite	2
Biotite gneiss	4

Source: Author's Analysis, 2022

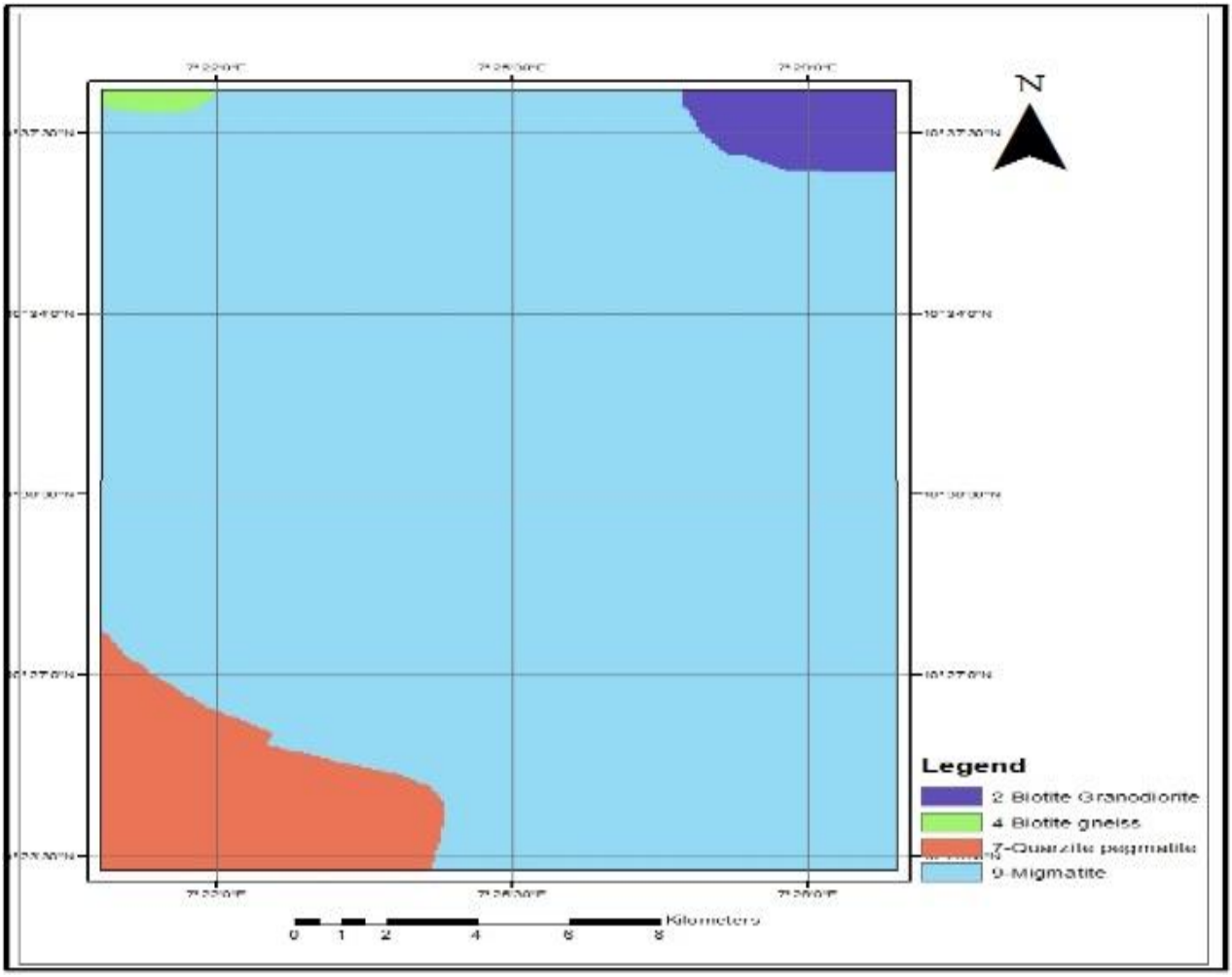


Figure 9: Classified Geologic Rock Types of Kaduna Metropolis

Source: Author's Analysis, 2022

Drainage

DRASTIC Ratings as shown in Table 10 was assigned to each class of the drainage density (Table 9) based on each characteristic and how it affected groundwater accumulation. A classified drainage density map was obtained as shown in Figure 10 (b) while the drainage density pattern is shown in Figure 10 (a).

Table 9: Drainage Density Classification

Drainage Density (km)	Classes
0- 46.85	Very low
46.86- 131.64	Low
131.65- 214.19	Moderate
214.20- 305.67	High
305.68- 566.72	Very high

Source: Author's Analysis, 2022

Table 10: DRASTIC Ratings for Drainage density

Drainage Density (km)	Classes	DRASTIC Ratings
0-46.85	Very low	10
46.86- 131.64	Low	7
131.65- 214.19	Moderate	5
214.20- 305.67	High	2
305.68- 566.72	Very high	1

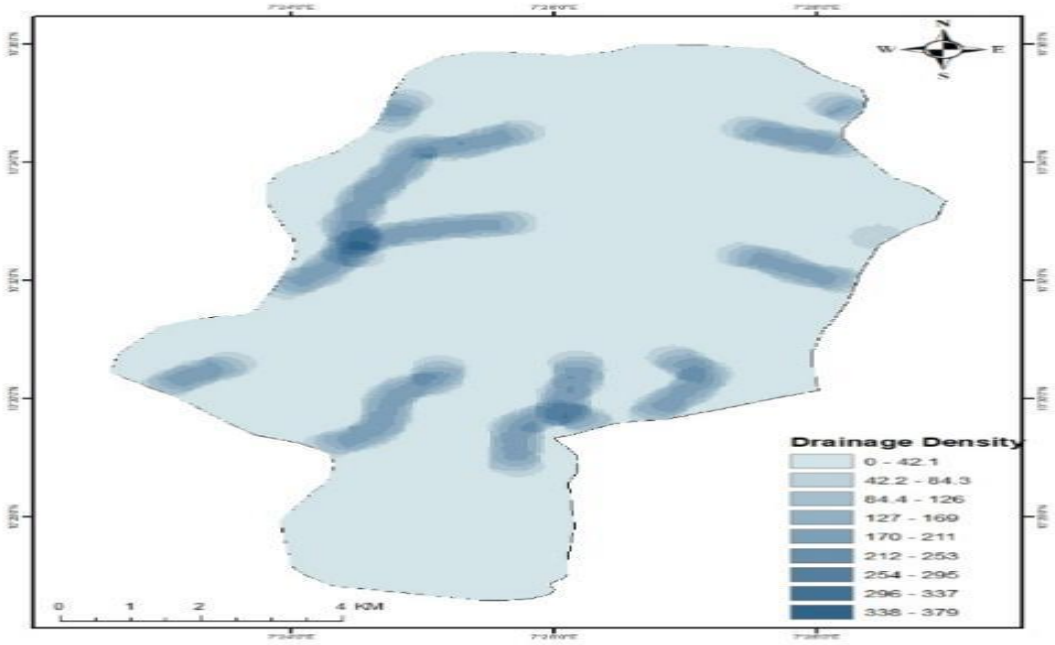


Figure 10 (a): Drainage density Pattern of Kaduna Metropolis

Source: Author's Analysis, 2022

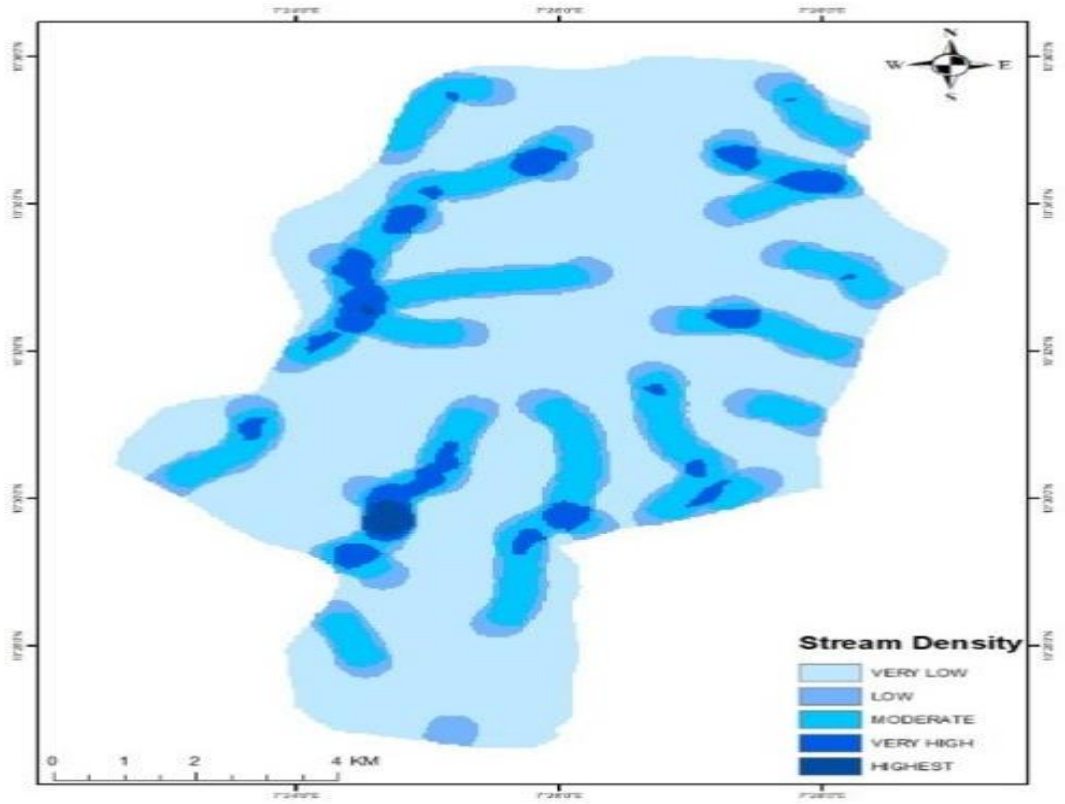


Figure 10 (b): Classified Drainage Density Pattern of Kaduna Metropolis

Source: Author's Analysis, 2022

Categorization of Groundwater Producing Zones

Groundwater Potential Map

All the hydrogeological factors were assigned DRASTIC Weight as shown in Table 10 and Figure 11 to show their importance to groundwater occurrence in the study area. The geology of the study area had the most significant factor for groundwater accumulation as contained in table 11 considering the weighted value calculated. Other hydrogeological factors such as slope, soil texture, drainage density, land use-cover and water bodies also played important role in groundwater replenishment as shown on the basis of the weighted values. The ground water potentials of the study area was also evaluated and its depicted in Figure 12.

Table 11: Weighted Table Overlay

RASTER	WEIGHT	ATTRIBUTES	RATINGS
Geology	5	Migmatite	9
		Schist QuartizitePagmatite	7
		Biotite Gneises	4
		Biotite Granodiorite	2
Slope	4	Flat	10
		Gentle	9
		Moderate	5
		Steep	3
		Very Steep	1
Soil Texture	3	Sandune	10
		Sandy Loam	8
		Sandy Clay	6
Drainage Density	2	No Drainage	10
		Low Drainage	7
		Moderate	5
		High Drainage	2
		Very High Drainage	1
Land use-cover	1	Vegetation	10
		Farmland	8
		Water Body	5
		Bare surface	3
		Settlement	1

Source: Author's Analysis, 2022

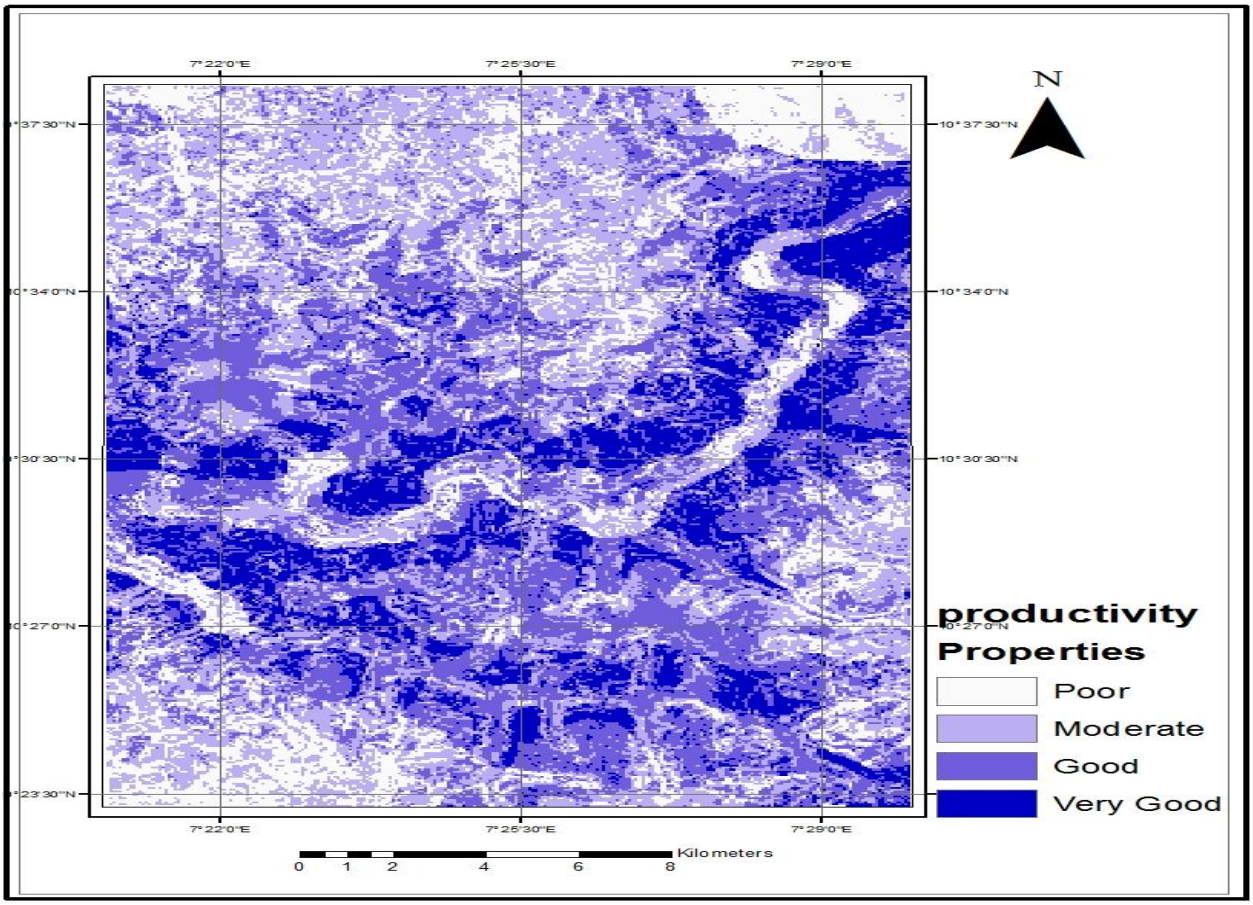


Figure 11: Groundwater production Status of Kaduna Metropolis

Source: Author's Analysis, 2022

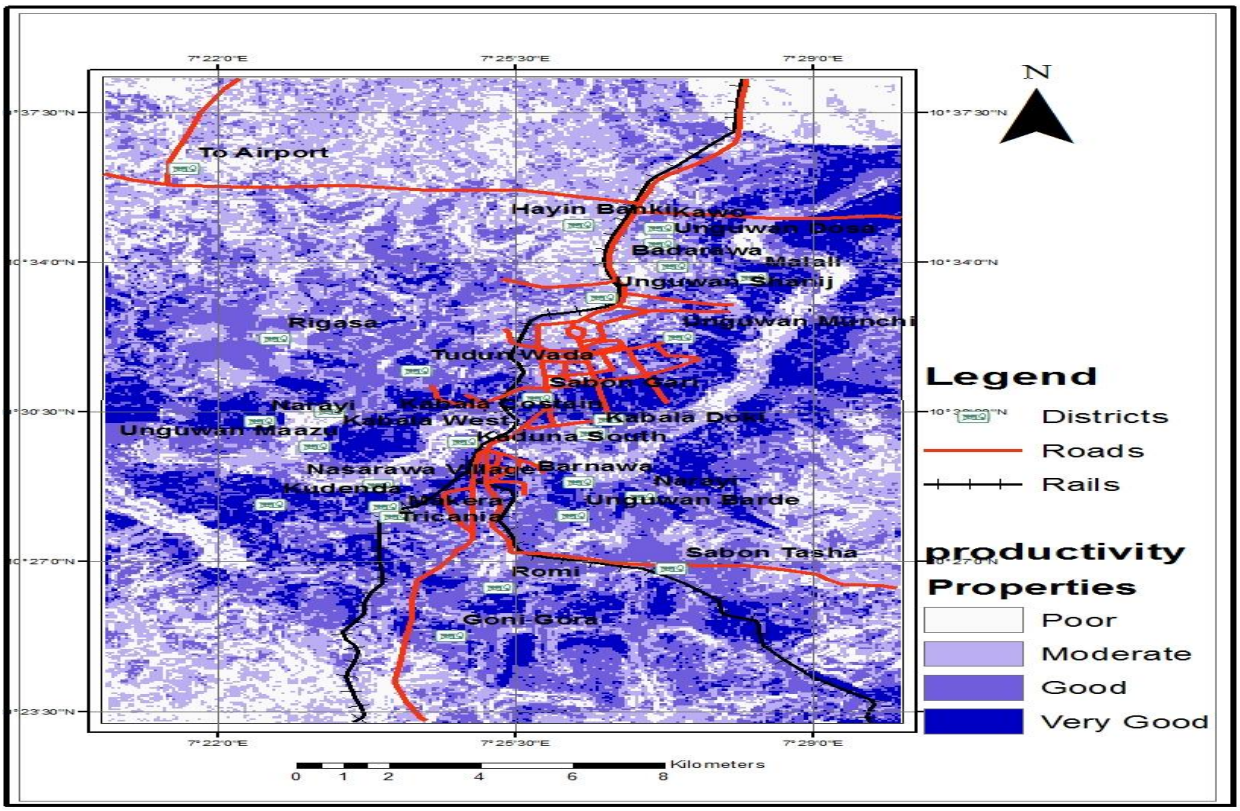


Figure 12: Groundwater Potential Zones of Kaduna Metropolis and Districts

Source: Author's Analysis, 2022

Table 12 shows the various districts within the study area where groundwater productivity was classified according to the groundwater availability.

Table 12: Table Showing Zones of Groundwater Productivity within the Metropolis

Groundwater Properties	**Groundwater Productivity zones**
Very Good	Angwan Munchu, Narayi, Kabala west, Angwan Barde, Dosa, Kawo, Kudenda, Some Parts of New Kaduna City.
Good	Rigasa, Romi, Sabon Tasha, NNPC, New Kaduna City
Moderate	New NDA, Hayin Banki, Airforce Base, Mando
Poor	Some parts of Hayin Banki, Airport Road, Mando

Source: Author's Analysis, 2022

Validation of Groundwater Productivity Map Using the Yield Data.

The existing borehole information from Eduvie, 2021 (Table 13) was juxtaposed with the information from the map values and the resultant table is presented in Figure 14. The distribution of the borehole sampled is as presented in Figure 13.

Table 13: Table Showing Borehole Information of selected parts of Kaduna Metropolis

s/n	Locations	X (^{0})	Y (^{0})	Expected Yield description from Map	Actual Yield from drilled borehole	Actual borehole yield description	Remarks
1	Barkin-Lahu	7.456	10.62	Good	0.8	Good	Coincide
2	National Teachers Institute	7.483	10.619	Moderate	0.6	Moderate	Coincide
3	Trade fair complex	7.483	10.605	Good	1.2	Very good	Not Coincide
4	Angwan-Kaji	7.455	10.6	Moderate	0.2	Poor	Coincide
5	Dalet Barracks	7.455	10.595	Poor	0.3	Poor	Coincide
6	Airforce Base	7.433	10.607	Good	0.7	Good	Coincide
7	Hayin-Banki	7.44	10.597	Moderate	0.5	Moderate	Coincide
8	Rafin Guza	7.461	10.591	Moderate	0.2	Poor	Not Coincide
9	Angwan-Dosa	7.451	10.577	Poor	0.4	Poor	Coincide
10	NDA Barracks	7.437	10.572	Moderate	0.5	Moderate	Coincide
11	Water Resource Int.	7.387	10.584	Good	1.5	Very good	Not Coincide
12	Airport Road	7.368	10.612	Good	0.7	Good	Coincide
13	Badarawa	7.454	10.586	Poor	0.4	Poor	Coincide
14	Malali	7.468	10.552	Poor	0.3	Poor	Coincide
15	Arewa House	7.452	10.552	Poor	0.8	Good	Not Coincide
16	Angwan Rimi	7.464	10.535	Moderate	0.5	Moderate	Coincide
17	Muritala Square	7.448	10.533	Very Good	1	very good	Coincide
18	Kaduna State University	7.436	10.526	Good	0.6	Moderate	Not Coincide
19	Police College	7.452	10.523	Good	0.6	Moderate	Not Coincide
20	Central Market	7.425	10.514	Very Good	1	very good	Coincide
21	Tudun Wada	7.41	10.531	Moderate	0.6	Moderate	Coincide
22	Rigasa	7.383	10.602	Poor	0.7	Good	Coincide
23	Kabala West	7.395	10.52	Good	0.8	Good	Coincide
24	Angwan Muazu	7.386	10.5	Moderate	0.6	Moderate	Coincide
25	Living Faith Church	7.444	10.486	Moderate	0.6	Moderate	Coincide
26	Barnawa	7.443	10.48	Good	0.7	Good	Coincide
27	Narayi	7.459	10.476	Good	0.7	Good	Coincide
28	Psychiatric Hospital	7.428	10.467	Good	0.8	Good	Coincide
29	Trikania	7.395	10.47	Very Good	0.5	Moderate	Not Coincide
30	Kudenda	7.373	10.474	Good	0.8	Good	Coincide
31	Television Garage	7.428	10.45	Good	0.8	Good	Coincide
32	Angwan Sunday	7.464	10.465	Good	0.8	Good	Coincide
33	Sabon Tasha	7.464	10.447	Good	0.7	Good	Coincide
34	Kamazo	7.495	10.448	Moderate	0.7	Good	Not Coincide
35	Gbagi Village	7.448	10.441	Moderate	0.6	Moderate	Coincide

36	AngwanRomi	7.427	10.44	Moderate	0.6	Moderate	Coincide
37	Goni Gora	7.418	10.417	Moderate	0.6	Moderate	Coincide
38	NNPC	7.392	10.435	Very Good	1	very good	Coincide
39	HayinBanki	7.495	10.407	Moderate	0.6	Moderate	Coincide
40	Kabala West	7.442	10.577	Moderate	0.5	Moderate	Coincide
41	U. Rimi Central Msq.	7.389	10.497	Good	0.7	Good	Coincide
42	Badarawa	7.463	10.53	Good	0.7	Good	Coincide
43	Angwan. Kanawa	7.464	10.561	Good	0.7	Good	Coincide
44	Kawo	7.443	10.559	Moderate	0.8	Good	Coincide
45	Kawo New Ext	7.47	10.585	Very Good	0.3	Poor	Not Coincide
46	Ahmed Aminu	7.473	10.587	Good	0.8	Good	Coincide
47	HayinBanki	7.476	10.599	Good	0.6	Moderate	Not Coincide
48	Kawo Market	7.472	10.559	Good	0.8	Good	Coincide
50	Rafingusa	7.47	10.599 8	Good	0.7	Good	Coincide

Source: Author's Analysis, 2022

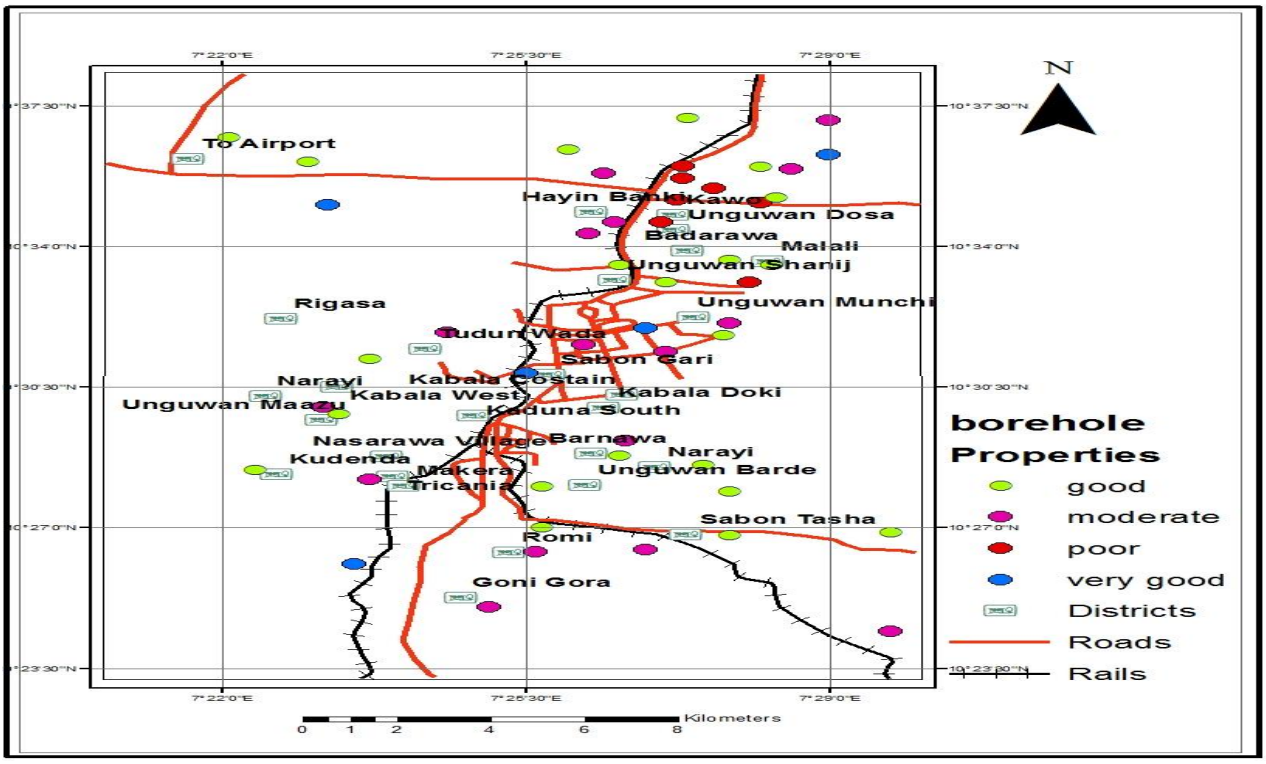


Figure 13: Borehole Distribution of Kaduna Metropolis

Source: Author's Analysis, 2022

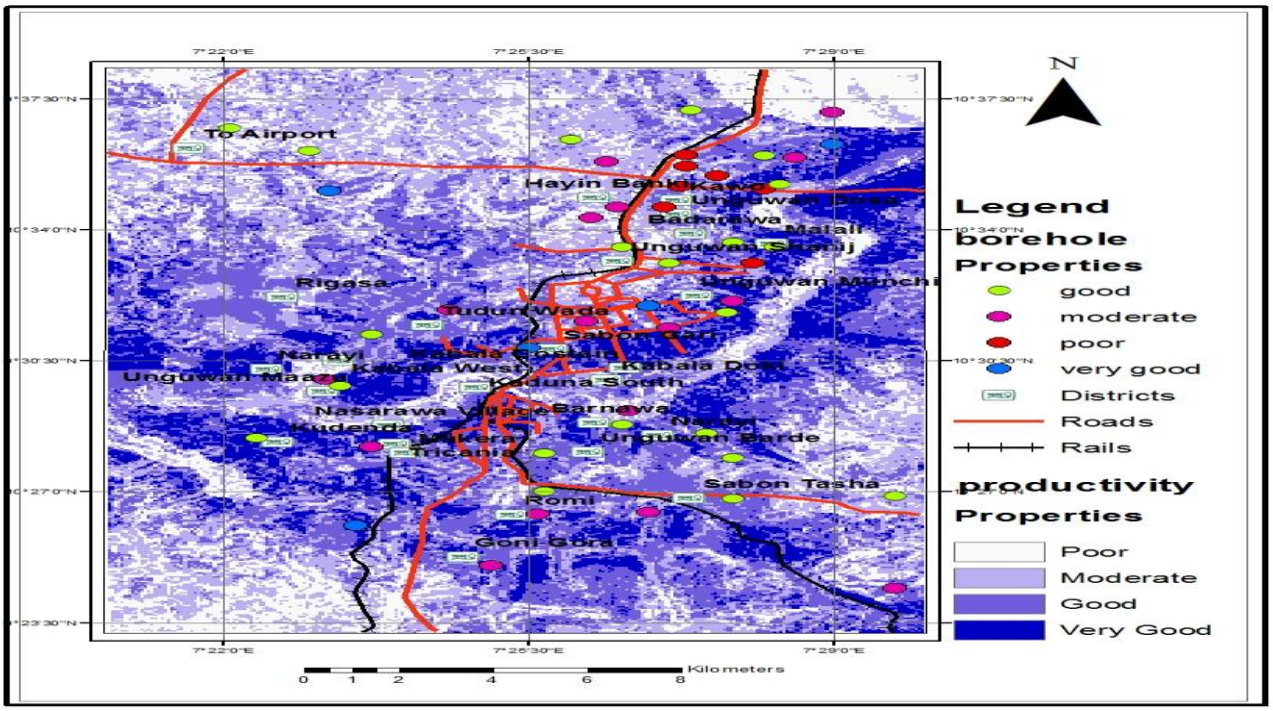


Figure 14: Correlation of Borehole and Groundwater Potential of Kaduna Metropolis

Source: Author's Analysis, 2022

The summary of the borehole yield is as shown in Table 14.

Table 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	Percentage
Very good	1.0-2	5	3	60%
Good	0.7-0.9	22	18	81.81%
Moderate	0.5-0.6	17	12	70.58%
Poor	0.1-0.4	6	4	66%
Total		**50**	**38**	

Source: Author's Analysis, 2022

To validate the groundwater productivity of the study area if the model used was successful, was determined by Anderson et al., (1976) accuracy assessment

$$\frac{\sum \text{BCYM}}{\sum \text{ABD}} X100$$

Where ∑BCYM= Total number of boreholes that coincide with yield map

∑ABD = Total number of actual drilled boreholes.

The Accuracy of Validation=$\frac{38}{50} X\ 100 = 76\%$

The validation accuracy obtained suggests that the method applied for this study produced significantly accurate results.

Discussion of Results

The research has demonstrated the application of using remote sensing and GIS combined with the modified DRASTIC model technique to generate the groundwater producing zones of Kaduna Metropolis. This is in agreement with Chowdhury, et al., (2009) who did a similar thing in West Medinipur district, West Bengal, India.

The research also shows that the geology, geomorphology, slope, drainage density land use-cover and the soil texture have interrelated relationships which are major and minor determinants of groundwater availability in any particular basement rock respectively which affirm the work of Nag& Anindita (2011) in delineating groundwater potential zones in Dwarakeswar Watershed Bankura District, West Bengal.

The geology of the area was the major chief determinant of groundwater accumulation in the area has responded overtime to tectonic stress caused by earth movement resulting to weathering as a result of the age of each rock as well as fractures and joints which will result to permeability as well as movement and accumulation of water beneath the earth surface. This is in agreement with (Olayinka and Olorunfemi, 1992) which described that groundwater are located in the basement fractured rocks and also in the fracturing, fissuring and jointing systems of the bedrock

From the groundwater productivity map generated, four major group of groundwater producing levels were delineated and was grouped as: very good, good, moderate and poor. The various patterns shown reflect the concept of the model that was used for the research. Areas that are very good and good groundwater producing zones occur mainly at areas that are favourable in terms of geology and geomorphology. For geology, they occur mainly in areas of migmatite. This is because the migmatite tend to have better potential because of the cleavage foliations. Thus, their permeability is often enhanced. Areas with moderate are attributed to contributions from the combination of slope, land use/cover and landforms. While areas of poor groundwater producing zones are spatially distributed along highlands and lithology. This result is also in

tandem with Edet, et al., (1994) in their study lineament analysis for groundwater exploration in Precambrian Obana Massif and Obudu Plateau.

Conclusion

This research combined Remote Sensing and GIS within a DRASTIC Model for the assessment, evaluation and analysis of spatial distribution of ground water producing zones of Kaduna Metropolis and importantly the groundwater producing zones of Kaduna Metropolis have been produced using six thematic maps from exiting data and field data; generally demonstrates that GIS and Remote sensing techniques combine with DRASTIC Model in addition to field data could be used for the assessments of ground water producing zones in an area and; it can be considered as a time and cost-effective tool for delineations and identification groundwater producing zones. The study therefore recommends that remote sensing data are powerful tools to improve our understanding of groundwater systems and should always be deployed. Although it is unable to measure hydrogeological properties directly, they provide continuous detailed terrain information and allow the mapping of surface features significant to groundwater development therefore it is important to incorporate them in the data collection stage of groundwater exploration works. From the research, the extraction of lineaments was a challenge which plays a very important role in determining groundwater producing zones. Effort should be made in the extraction of lineaments for better interpretation and analysis.

Although six factors were used to determine groundwater producing zones, other factors that affect groundwater accumulation should be incorporated in the analysis for more accuracy.

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