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DELINEATION OF GROUNDWATER POTENTIAL ZONES IN KADUNA METROPOLIS, NIGERIA

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ABSTRACT

The scarcity of potable surface water in the Kaduna metropolis has resulted in a high dependence on reliable fresh groundwater. This has led to an increasing drilling of boreholes some of which have failed due to poor groundwater prospecting before drilling. The main aim of this study is to delineate the groundwater potential zones in Kaduna metropolis. The factors considered for this were lineament, drainage, elevation, slope, rainfall, soil, land use/ land cover and geology. Thematic maps for each of these factors were generated and the Analytical Hierarchical Process (AHP) was used to weight the various factors according to their influence on the occurrence of groundwater in the study area. The weighted index overlay was carried out and the groundwater potential map produced was classified into; very low, low, moderate and high groundwater potential zones covering 29.4%, 36.13%, 25.55% and 8.88% of the study area respectively. The results showed that lineament density and drainage density with weight percentages of 27% and 22% respectively were the major contributing factors towards the occurrence of groundwater in the study area. Rainfall and land use/ land cover with 4% each were the least contributing factors. The high groundwater potential zone was spread all round the study area but occurred mostly in the northern part of Kaduna metropolis. It was seen that the northern part of the metropolis had the best groundwater potential and would be the most suitable location for the exploitation of potable water for urban use.

Keywords: Groundwater, Groundwater potential zones, Weight, Analytical Hierarchical Process

INTRODUCTION

Over one billion people in the world lack access to an adequate supply of safe water for household use. It is estimated that around 700 million people in 43 countries suffer from water scarcity (Hameeteman, 2013). The global demand for water has been increasing at a rate of about 1% per year as a function of population growth, economic development and changing consumption patterns, among other factors, and it will continue to grow significantly over the next two decades. Water is the most essential resource for the survival of humans after air (Yusuf and Oladipo 2012). Fresh water occurs either as surface water or groundwater, the latter being the most abundant (Olaniyan, Agunwamba and Ademiluyi, 2010).

Groundwater is a significant global resource, comprising of about 96% of the earth unfrozen fresh water (Oke and Aladejana, 2012). Groundwater is the water found underground, under the zone of saturation in the cracks and soil pore spaces in soil, sand and rocks (The Groundwater Foundation, 2018). Groundwater is not uniformly distributed all over and is limited in hard rock terrains (Suryabhagavan, 2017) which make its quantity and quality to vary with location. Therefore, it is important to assess the disparity of groundwater occurrence in order to enhance its exploration as well as conserve and manage it. In doing so, proper study of it in certain terrains must be carried out to improve the knowledge on its occurrence. This will in turn lead to its effective exploitation for human use. Groundwater is one resource that cannot be observed directly from the surface as a result of its hidden nature. Its study is therefore chiefly dependent on the use of indirect methods i.e. the study of the dynamics of the various factors that contribute to its occurrence and accumulation (Mangey, 2017).

The ever increasing population in developing countries especially in Africa has put a strain on essential resources. With the current increase in urban, agricultural and industrial, the strain on these essential resources, most especially water cannot be overemphasized. However, the poor economic situation and lack of improvement of many basic infrastructural facilities to meet the increasing demand on the parts of the government warrants the need for individuals and local communities to look for alternatives to the conventional public water supply system (Fashae, Tijani, Talabi, and Adedeji, 2014). This means individuals and organizations have to get water from other sources which include rivers, streams, wells and boreholes. The main alternative source of water in Northern Nigeria is groundwater as opposed to surface water which is sometimes seasonal or non-existent (Olaniyan *et al*., 2010).

The Kaduna State Ministry of Economic Planning (KSMEP) in its state development plan for 2014-2018 released in September 2013 noted that only 32% of the urban population in the state receives potable water from the municipal water supply system daily while less than 20% of the inhabitants of the semi-urban areas have access to potable water. The service coverage in the rural areas is estimated at only 11%. Estimates show that only 23% of the entire Kaduna state population has access to municipal water supply. It further stated that of the 2,667 boreholes built by the Ministry of Water Resources only 20% were active and productive. Based on this, there is acute shortage of adequate water supply in the state and the metropolis (KSMEP, 2013). One of the reasons attributed to this large failure is the lack of proper knowledge of the groundwater potential of the state (Afuwai, Lawal, Sule and Ikpokonte, 2015).

Kuhiyop (2016) carried out a geospatial investigation of the groundwater potential zones in Kachia Local government area of Kaduna state. The study attempted to identify the groundwater potential zones in Kachia LGA of Kaduna using remote sensing and GIS techniques as well as the resistivity method for validation. The study made use of thematic maps like lineament, geology, land use, drainage, slope, elevation, rainfall and soil as GIS layers while weights were assigned based on pairwise comparison of factors that appear to be important in processing recharge of water and groundwater potential. The result of the analysis showed that rainfall and lineament density were identified as the highest factors contributing to groundwater prospects with 34% and 24% respectively. The groundwater potential zones were classified into very good, good, moderate, low and very low covering 14.1%, 22.4%, 15%, 23.9% and 24.6% of the study area respectively. It further showed that the higher the aquifer thickness and depth the better the groundwater potential. The location of this study is different from the present study as well as the effects of the factors controlling the occurrence of groundwater.

Therefore the delineation of groundwater potential zones in Kaduna metropolis is necessary to provide accurate information on the location of groundwater potential zones in the area as a research of this kind has not been conducted in the study area prior to this. This will in turn help reduce the rate of failed water projects in the metropolis. The main aim of this study is to delineate the Groundwater potential zones in Kaduna Metropolis, Nigeria. This aim would be achieved by; producing and weighting thematic maps of factors that affect the occurrence of groundwater in Kaduna metropolis; using the weighted index overlay to produce a groundwater potential map of the study area; measuring the spatial extent of the groundwater potential zones; and explaining the distribution of the groundwater potential zones.

The Study area

Kaduna metropolis is geographically situated between Latitudes 10º 16ˈ to 10º 45ˈ N of the Equator and Longitudes 07º 10ˈ to 07º 40ˈ E of the Greenwich Meridian. It comprises wholly of Kaduna North and Kaduna South with parts of Igabi and Chikun Local Government areas. It covers an area extent of approximately 260 square kilometres. The distance between the Eastern and Western limits of the metropolis is approximately 13.7 km and between the North and South is approximately 20 km (Dodo, 2008). Figure 1 shows Kaduna metropolis which is the study area. Kaduna Metropolis experiences two distinct seasons which are the wet and the dry seasons. The climate of Kaduna is 'Aw' as coded by Koppen with rainfall of about 1200 mm annually which typically last between 5 to 6 months (April to September). Temperature is generally hot throughout the year with the exception of slight period of cold and dry season from November to February (harmattan). Its relative humidity ranges between 20% and 30% in January and rises to between 60% and 80% in July (Mohammed and Aliyu, 2014).

The geology of Kaduna metropolis is made up of rocks of the Nigerian Basement Complex. It comprises of rocks of the migmatite-gneiss complex, meta-sedimentary series (Schist belts), Older Granites, Younger Granites and Newer Basalts. The predominant rock types in the study area have secondary porosity which is as a result of lineaments present. Lineaments are manifestation of linear features that can be identified directly on the rock units or from remote sensing data. Lineaments and their intersections play a significant role in the occurrence and movement of groundwater resources in crystalline rocks (Prasad, Mondal, Banerjee, Nandakumar and Singh, 2008). Kaduna metropolis lies within the savannah belt of Nigeria and is predominantly made of the Guinea Savannah. It is the largest of all vegetation belts in Nigeria and is characterized by the presence of tall grasses, umbrella shaped canopy trees and deciduous trees with tiny leaves to reduce transpiration. The drainage pattern is purely dendritic, with river Kaduna as the principal drainage line. Kaduna Metropolis is located within the floodplain of River Kaduna, a low lying terrain spanning 73-167m above sea level (Aliyu and Sulieman, 2016). It is drained by River Kaduna and its tributaries such as Gora, Mushi, Ruwauwei, Keke, Danhora, Kuba, Kuyi and Romi. The topography of Kaduna metropolis consist of a rolling part terrain with little relief situated about 30.48 meters above the 609.6 meters contour line above sea level (Nyam Jim, 2016). It is characterised by extensive gentle slopes, undulating plains with vast rolling lowland plains generally below 610m above sea level (Ndabula, 2006). Kaduna metropolis has an estimated population of 1,047,757 based on 2018 projection (World Bank Group, 2018).

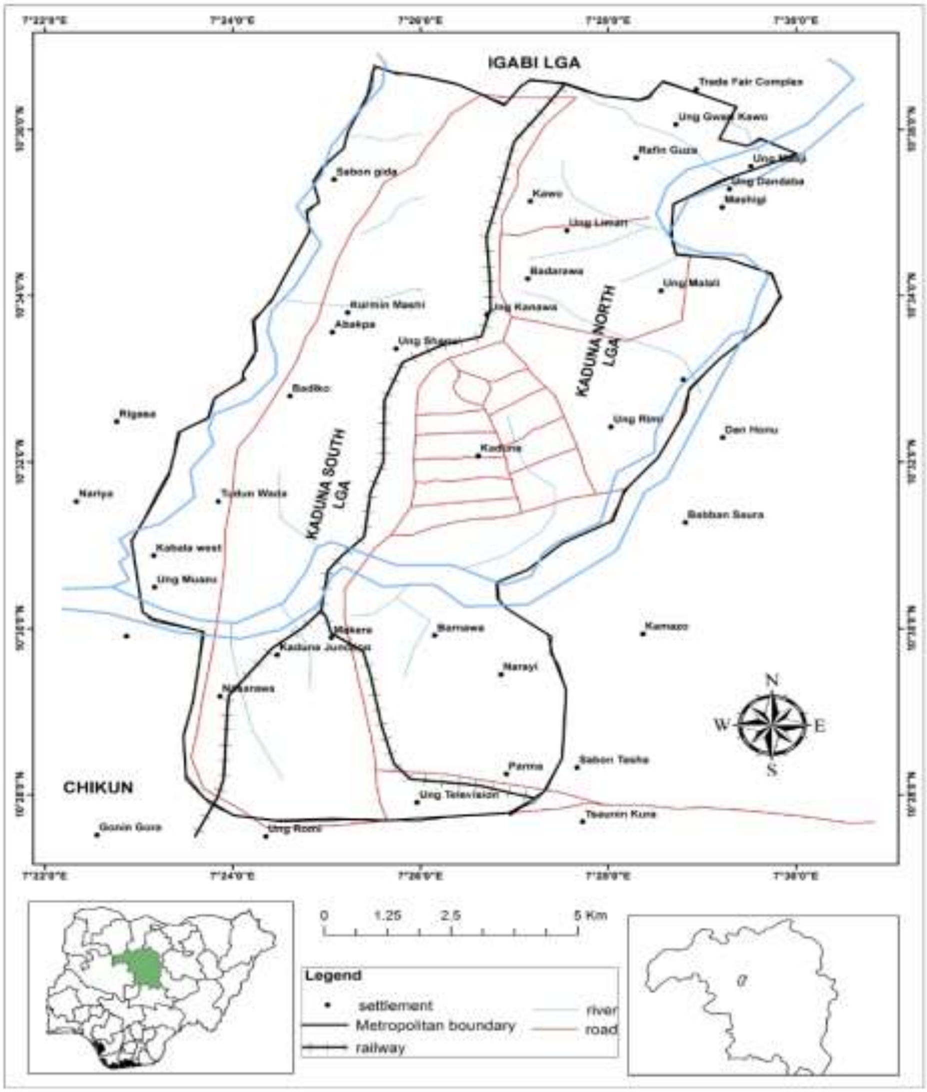

Fig. 1: Kaduna Metropolis (Study Area)
Source: Adapted from Akpu and Tanko (2017)

MATERIALS AND METHODS

This study made use of Landsat 8 OLI of March 2018 and Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) from USGS, metrological data from Nigerian Metrological Agency (NIMET) and National Aeronautics and Space Administration (NASA), soil map from Centre for World Food Studies Inventory and geological map form Nigerian Geological survey Agency.

Thematic maps of factors that affect the occurrence of groundwater in the study area were generated. The factors considered were geology, drainage, lineaments, soil, rainfall, elevation, slope and land use/ land cover. The DEM was used to prepare the slope map using the slope function from the spatial analyst toolbox in ArcGIS 10.4 while the elevation map was brought about by changing the symbology of the DEM. The drainage map of the study area was produced using the Arc Hydro extension of ArcGIS 10.4 from the DEM. The lineament map was produced using a PC1 image in PCI Geomatics 14. The PC1 image used was prepared by combining 7 bands of the Landsat OLI images in ENVI 4.5. The principal Component tool was used to transform the bands to a Principal component analysis image. The line function of the algorithm librarian in PCI Geomatics 15 was used to compute the lineaments present in the study area. The line density function of the spatial analyst toolbox of ArcGIS 10.4 was then used to produce the lineament density map from the lineament map.

The geological map was first scanned and georeferenced using Global Mapper 15 after which it was digitized in ArcGIS 10.4 to produce the final Geology map. The land use/land cover map was produced by carrying out supervised classification in ArcGIS 10.4 on a LANDSAT 8 OLI image of the study area. Supervised classification using Maximum Likelihood Classification was carried out in ArcGIS 10.4. The land use/land cover were classified into vegetation, built-up area, bare land, water body and agricultural area based on USGS classification scheme (Anderson's classification, 1971). The average annual rainfall of the study area was computed using the average rainfall of 2017 and 2018 obtained from NIMET and NASA. Ordinary Kriging interpolation method was used to prepare the rainfall map in ArcGIS 10.4.

These maps were then reclassified and weighted using the Analytical Hierarchical Process. The reclassified maps were overlaid using the weighted index overlay in the spatial analyst tool of ArcGIS. According to Prasad, Mondal, Banerjee, Nandakumar and Singh (2008), this technique is efficient in the study of locations of geographic phenomena together with their spatial dimension and associated attributes and is given by:

GWP= Σ **WiXi**cf

Where GWP = Groundwater potential; Wi = Weight for each map score (weight for each thematic map) and Xicf = Individual map (reclassified map)

The output image of the overlay analysis showed the various Groundwater potential zones in the study area.

RESULTS AND DISCUSSIONS

The extent to which each factor affects the occurrence of groundwater was determined and weights were assigned to each factor accordingly.

Slope

Slope affects the rate of surface run off and infiltration of an area. The slope of the study area was classified in the following categories: 0-1.3 % (Nearly Flat), 1.4-2.7 % (gentle slope), 2.8-3.8 % (Moderate slope), 3.9-7.5 % (Strong Slope) with each covering 17.2 Km^2 (13.2%), 61 Km^2 (46.8%), 37 Km^2 (28.4 %) and 15.2 Km^2 (11.7%) respectively (see Figure 2). A pairwise comparison of the various classes of slope was done and the result is presented in Table 1.

Table 1: Pairwise comparison and weighting of slope classes

Slope	0-1.3	1.4-2.7	2.8-3.8	3.9-7.5	Weight	Weight (%)	Potential
0-1.3	1	3	6	8	0.59	59	Very good
1.4-2.7	1/3	1	3	6	0.26	26	Good
2.8-3.8	1/6	1/3	1	2	0.10	10	Poor
3.9-7.5	1/8	1/6	1/2	1	0.05	5	Very poor

Source: {Author's Analysis, (2019)}

The result of the analysis shows that areas with low slope (0-1.3%) have the highest weight. The slope gradient directly influences the infiltration of rain water (Yeh, Cheng, Lin and Lee, 2016). Higher slope % rise produces a smaller recharge because water flows rapidly down a steep slope during rainfall, so it does not have sufficient time to infiltrate the surface and recharge the saturated zone. As a result, areas with high slope gradient will be less favourable for the occurrence of groundwater while the lowest slope gradient will be the most favourable. It is for this reason the slope classes were classified from very good to very poor according to their potential to contribute to the occurrence of groundwater.

Elevation

It was found that the highest elevation was 650 metres above sea level, located in the north central part of the study area while the lowest point of 564 metres above sea level was towards the south. The elevation of the study area was classified into five which are: 564-580m, 581-600m, 601-615m, 616-630m and 631-650m covering 20.3 Km^2 (15.6 %), 32.8 Km^2 (25.1%), 33.4 Km^2 (25.6%), 27.1 Km^2 (20.8%) and 16.8 Km^2 (12.9%) of the study area respectively (see Figure 3). The way the various classes of elevation affects the occurrence of groundwater is shown in Table 2.

Table 2: Pairwise comparison and weighting of the various classes of elevation

Elevation	564-580	581-600	601-615	616-630	631-650	Weight	Weight (%)	Potential
564-580	1	3	4	5	8	0.49	49	Very good
581-600	1/3	1	2	4	6	0.25	25	Good
601-615	¼	½	1	2	4	0.14	14	Moderate
616-630	1/5	¼	1/2	1	2	0.08	8	Poor
631-650	1/8	1/6	1/4	1/2	1	0.04	4	Very poor

Source: {Author's Analysis, (2019)}

The lowest point (564-580) of the study area had the highest weight of 49% and consequently the best groundwater potential. The least potential was seen at the highest elevation point (631-650) as higher grounds do not have the best potential. This is because the higher a point above sea level the less the probability of finding groundwater.

Geology

The geology of the study area is made up of two major rock types which are the migmatite gneiss which forms the bedrock of the majority of the study area covering 11.4 Km (88.2 %) and granite which forms the remainder of the study area (see Figure 4). The result of the pairwise comparison and weighting of the types of geology present in the study area is presented in Table 3.

Table 3: Pairwise comparison and weighting of geology classes

Geology	Migmatite	Granite	Weight	Weight (%)	Potential
Migmatite	1	1/2	0.33	33	Poor
Granite	2	1	0.67	67	Fairly poor

Source: {Author's Analysis, (2019)}

Both rock types in the study area do not have good water bearing capacity and their ability to retain water is solely based on the presence of faults, fractures, joints and weathering. Granites in the study area were observed to have the said structures when compared with the migmatites. It can be seen that granite has the highest weight of 67% and is more likely to be water bearing when compared to the migmatite. Consequently, the rock types present were classified into poor and fairly poor based on their groundwater bearing potential.

Rainfall

The mean rainfall for two years (2017 and 2018) was used to generate an average precipitation map of the study area. The years selected was based on the need to access 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 was divided into five groups: 1424-1467, 1468-1511, 1512-1554, 1555-1598 and 1599-1641 covering 67.9 Km^2 (52.1 %), 14 Km^2 (10.7 %), 9.3 Km^2 (7.2 %), 8.2 Km^2 (6.3 %) and 30.9 Km^2 (23.7 %) respectively (see Figure 5). The result of the pairwise comparison of the various classes of rainfall can be seen in Table 4. The southern part of the study area received the highest mean annual rainfall with an average range of 1599-1641 mm while the lowest was seen in the north with an average of 1424-1467 mm. The higher the rain fall received in an area the more the amount of water available to recharge the aquifers. The rainfall variations were classified from very poor to very good according to their potential to affect the occurrence of groundwater with the lowest average rainfall being very poor and the highest being very good.

Table 4: Pairwise comparison and weighting of rainfall classes

Rainfall	1424-1467	1468-1511	1512-1554	1555-1598	1599-1641	Weight	Wt %	Potential
1424-1467	1	1/2	1/3	1/4	1/5	0.06	6	Very Poor
1468-1511	2	1	1/2	1/3	1/4	0.10	10	Poor
1512-1554	3	2	1	1/2	1/3	0.16	16	Moderate
1555-1598	4	3	2	1	1/2	0.26	26	Good
1599-1641	5	4	3	2	1	0.42	42	Very Good

Source: {Author's Analysis, (2019)}

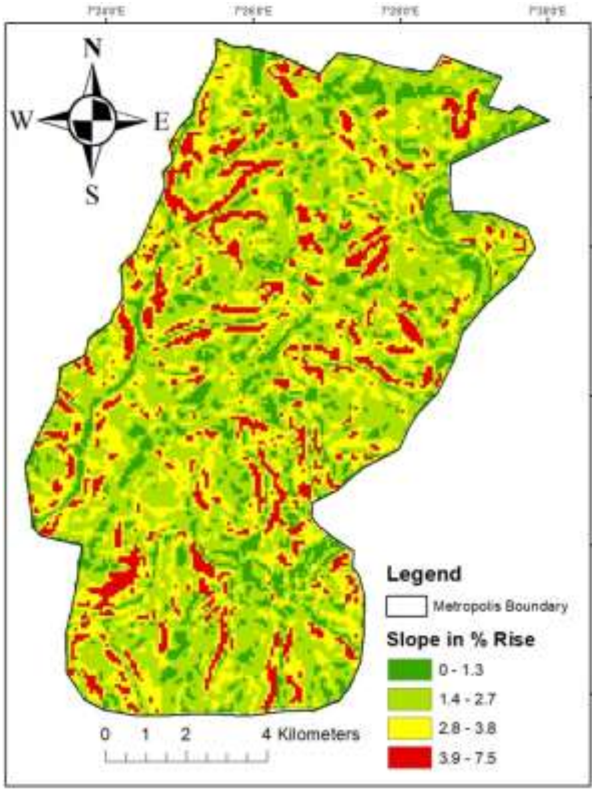

Fig. 2: Slope classes of the study area

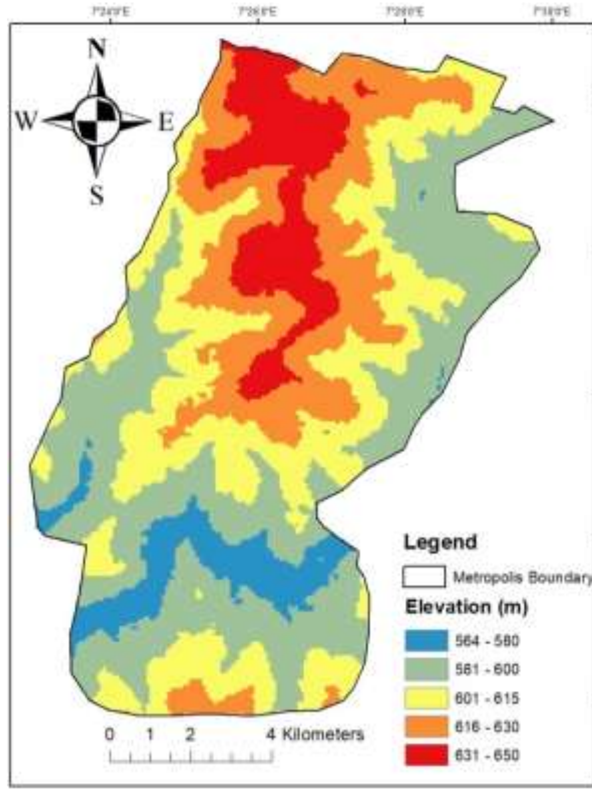

Fig. 3: Elevation classes of the study area

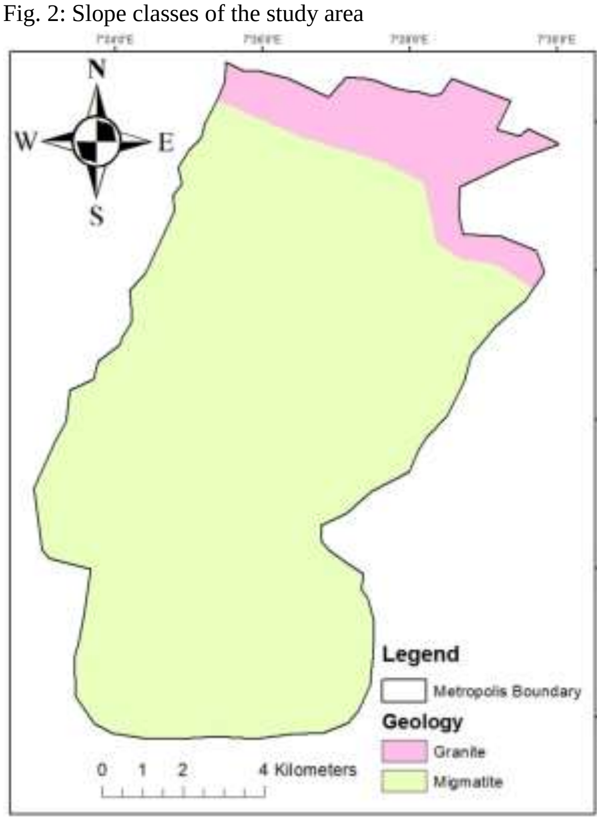

Fig. 4: Geology classes of the study area

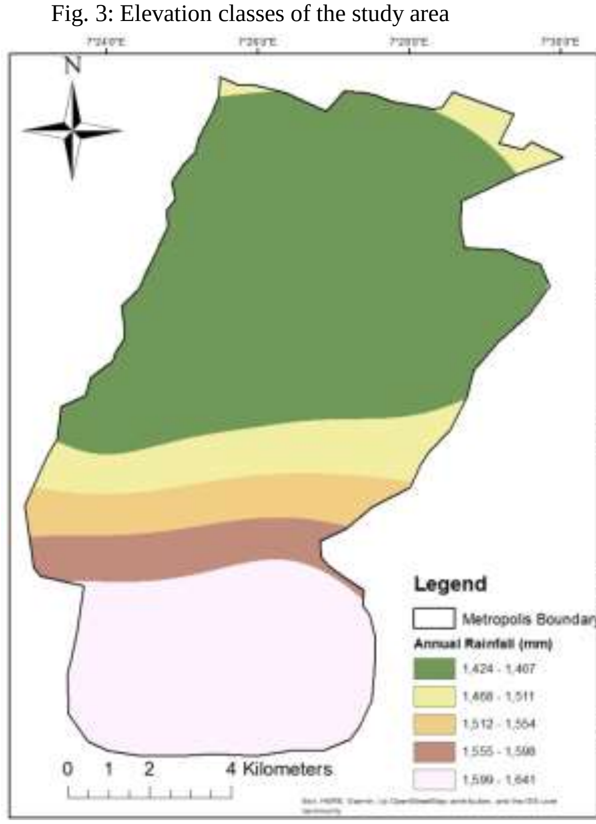

Fig. 5: Rainfall classes of the study area

Lineaments

The lineament density was calculated from the lineaments extracted and was classified into five groups based on frequency of occurrence. Bulk of the study area like Ungwar Rimi and Ungwar Television was made of places with little or no lineaments (0-0.5) which covered 73.2 % of the study area. The grouping of the lineaments density follows; 0-0.5, 0.6-1.1, 1.2-1.6, 1.7-2.2 and 2.3-2.7 covering an area extent of 95.4 Km^2 (73.2 %), 14.5 Km^2 (11.2 %), 17.1 Km^2 (13.2 %), 2.2 Km^2 (1.7 %) and 1 Km^2 (0.7 %) respectively (see Figure 6). The result of the pairwise comparison and weighting of the various lineament density classes can be seen in Table 5.

Table 5: Pairwise comparison and weighting of lineament density classes

Lineaments	0-0.5	0.6-1.1	1.2-1.6	1.7-2.2	2.3-2.7	Weight	Weight %	Potential
0-0.5	1	1/2	1/3	1/7	1/9	0.04	4	Very poor
0.6-1.1	2	1	1/2	1/4	1/7	0.07	7	Poor
1.2-1.6	3	2	1	1/2	1/5	0.12	12	Moderate
1.7-2.2	7	4	2	1	1/4	0.22	22	Good
2.3-2.7	9	7	5	4	1	0.55	55	Very good

Source: {Author's Analysis, (2019)}

Lineament is one of the major sources of secondary porosity. The areas with high lineament density were seen to have the highest weight 55% 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 favourable for groundwater occurrence. In an area where the average annual rainfall is above 1000 mm, groundwater potential would be a function of secondary porosity (Sander, 2007).

Drainage

The drainage density was computed from the drainage network and it was seen that the highest drainage density (119-200) occurred in the southern part of the study area. The different drainage density classes in the study area are as follows: 0-25, 26-50, 51-79, 80-118 and 119-200 each covering 30.3 Km^2 (23.3 %), 41.8 Km^2 (32.1 %), 34 Km^2 (26.1), 17.5 Km^2 (13.4 %) and 6.7 Km^2 (5.1 %) respectively (see Figure 7). The result of the pairwise comparison of the drainage density classes can be seen on Table 6.

Table 6: Pairwise comparison and weighting of drainage density classes

Drainage Density	0-25	26-50	51-79	80-118	119-200	Weight	Weight %	Potential
0-25	1	3	5	6	9	0.52	52	Very Good
26-50	1/3	1	2	4	7	0.24	24	Good
51-79	1/5	1/2	1	2	4	0.13	13	Moderate
80-118	1/6	1/4	1/2	1	2	0.07	7	Poor
119-200	1/9	1/7	1/4	1/2	1	0.04	4	Very poor

Source: {Author's Analysis, (2019)}

Areas of high drainage density have less infiltration because major part of the rainwater over the area is lost and hence acts as poor groundwater prospect. Areas of low drainage density permit more infiltration and recharge to the groundwater reservoir and this makes them good for groundwater prospect (Ndatuwong and Yadav, 2014). Areas with high drainage density will not allow for adequate infiltration of water as can be seen from the analysis and had the lowest weight of 4%. On the contrary, areas with drainage density between 0-25 had the highest weight of 52% and as a result highest the potential for groundwater occurrence. Drainage density is an inverse function of permeability as such is important in evaluating groundwater potential zones (Agaarwal *et al*, 2009).

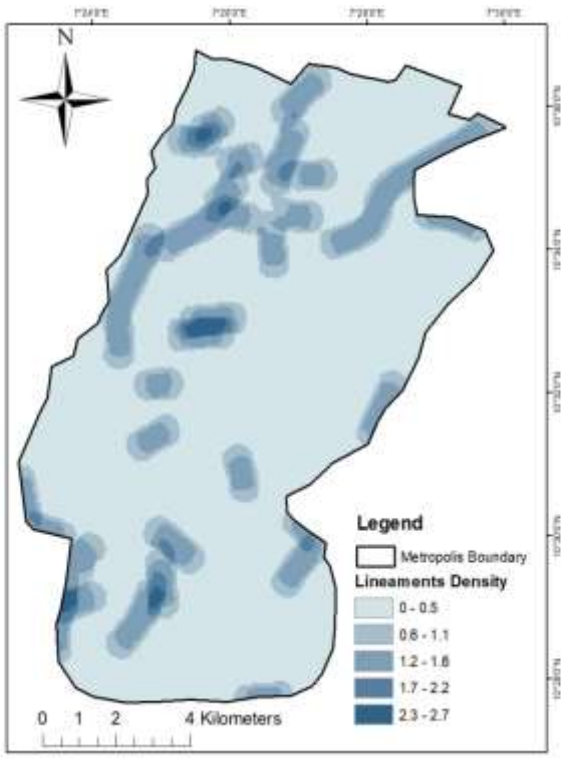

Fig. 6: Lineaments Density Grouping

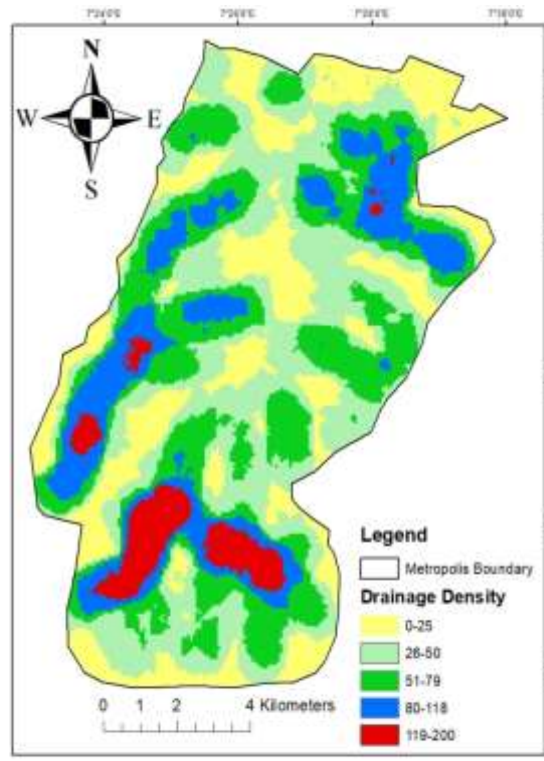

Fig. 7: Drainage Density classification

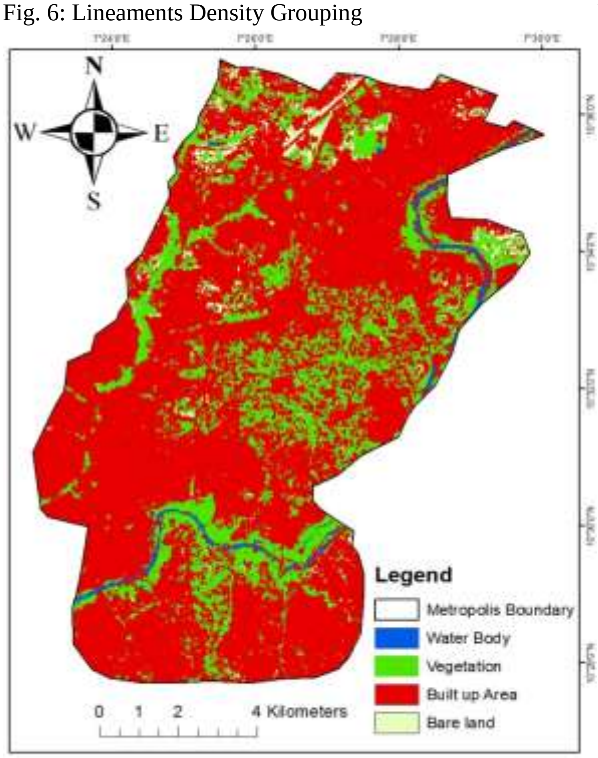

Fig. 8: Land Use/Land Cover of the study area

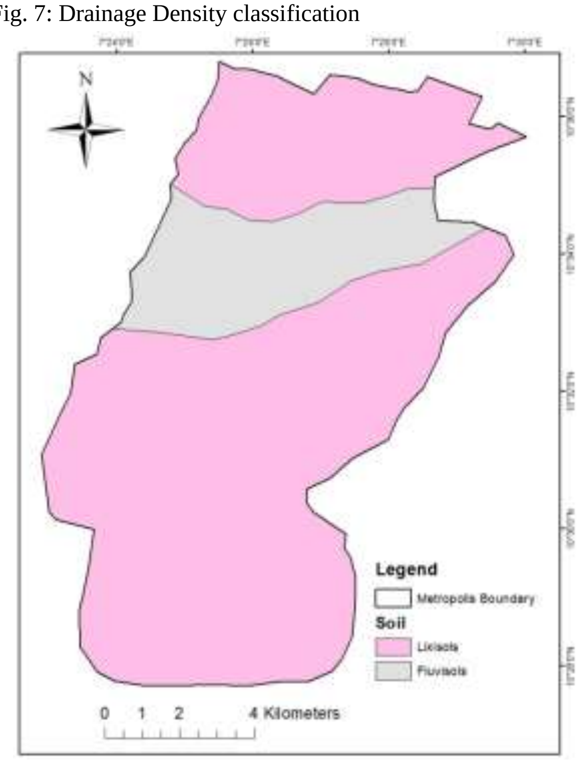

Fig. 9: Soil classes of the study area

Land use/land cover

The study area is mainly a built up area which makes up 75.8 % of the land use of the study area while water was the least with 1%. The different land use/land cover of the study area are water, vegetation, built up area and bare land with each covering an aerial extent of 1.4 Km^2 (1 %), 26.6 Km^2 (20.4 %), 98.8 Km^2 (75.8 %) and 3.5 Km^2 (2.7 %) respectively (Figure 8). Table 7 shows the pairwise comparison of the LULC classes. Water bodies had the highest weight of 57% while built up area had the lowest of 6%. Built up areas are not suitable for groundwater occurrence because human activities such as construction of concrete structures and deposition of impermeable waste seal the soil surface thereby preventing any form of infiltration. LULC plays a vital role in the development of groundwater resources because of its ability to influence hydrogeological processes such as infiltration, evapotranspiration, surface runoff, etc. (Fashae, Tijani, Talabi, and Adedeji, 2014).

Table 7: Pairwise comparison and weighting of LU/LC classes

LU/LC	Water	Vegetation	Built up area	Bare land	Weight	Weight %	Potential
Water	1	3	7	5	0.57	57	Very Good
Vegetation	1/3	1	5	3	0.26	26	Good
Bare land	1/5	1/3	2	1	0.11	11	Poor
Built up area	1/7	1/5	1	1/2	0.06	6	Very poor

Source: {Author's Analysis, (2019)}

Soil

Two major soil types are present in the study area; they are the lixisols and the fluvisols. The Lixisols was the more dominant soil type covering an aerial extent of 107.8 Km^2 (82 %) while the fluvisols covered the remaining 22.5 Km^2 (17.3 %) of the study area (see Figure 9). Table 8 shows the pairwise comparison between the two classes of soil present in the study area. Fluvisols have higher pore spacing and generally allows for easier infiltration of water unlike the lixisols which have a saturated clay base which doesn't allow for easy infiltration of water. The soil types present in the study area generally have low infiltration due to the prevalence of clay minerals which hamper the percolation of surface water into the subsurface.

Table 8: Pairwise comparison and weighting of soil classes

Soil	Lixisols	Fluvisols	Weight	Weight %	Potential
Lixisols	1	1/3	0.25	25	Poor
Fluvisols	3	1	0.75	75	Moderate

Source: {Author's Analysis, (2019)}

Distribution of Groundwater potential zones

The Groundwater potential zones in Kaduna metropolis was determined by integrating the weighted thematic maps of the factors affecting the occurrence of groundwater in the study area. The weighting was done using the Analytical Hierarchical Process in expertchoice 11. Table 9 shows the outcome of the weighting done. From Table 9 it can be seen that Lineament was weighted highest (27%) followed by Drainage (22%) and rainfall was the least alongside LULC with 4%. This was because when the average rainfall in an area is more than 1000mm per annum the recharge of groundwater would be a function of secondary porosity (Sander, 2007), vegetation (Shaban, Khawlie and Abdallah, 2006), permeability of top soil (Jha *et al.,* 2007) and topographic characteristics (Solomon, 2003; Jha *et al.,* 2007).

The final groundwater potential map produced can be seen in Figure 10. The map was reclassified into four potential zones which are; very low, low, moderate and high. The Areas with high groundwater potential are spread round the study area but is mostly in the northern part of the study area. This is in correspondence with the work of Olaniyan and Olorunnaiye (2013) who investigated the groundwater resources of Rafin Guzan in Kaduna North LGA using the resistivity method, which found the area to have good potential for groundwater. The high groundwater potential zones are seen in areas with low drainage density, high lineament density, low slope gradients and low elevations which is similar to the high groundwater potential zones delineated by Ali, Lal and Ahsan (2015) when they delineated groundwater potential zones in Allahabad district using remote sensing & GIS techniques. Both geology rock types present in the study area are naturally not good aquifers and as such depend on secondary porosity to aid recharge of groundwater. Similarly the soil types present are clayey and do not allow for the easy infiltration of water as such do not really affect the outcome of the groundwater potential map. The rainfall in the study area is also sufficient to recharge the groundwater assuming all factors are favourable.

The areas with very low to low groundwater potential were characterized by the presence of high drainage networks, low lineament density, high slope gradients and high elevation. They have low potential because areas characterized by high drainage density, low lineament density, high slope gradient and high elevation don't allow for the percolation of water.

Table 9: Pairwise comparison and weighting of groundwater controlling factors

	Lineament	Geology	Soil	LULC	Drainage	Slope	Elevation	Rainfall	Weight
Lineament	1	2	5	5	2	3	3	5	27
Geology	1/2	1	3	5	1/2	2	2	3	16
Soil	1/3	1/5	1	4	1/3	1/3	1/3	3	7
LULC	1/5	1/5	1/4	1	1/4	1/3	1/3	2	4
Drainage	1/2	2	3	4	1	3	3	5	22
Slope	1/3	1/2	3	3	1/3	1	1	2	10
Elevation	1/3	1/2	3	3	1/3	1	1	2	10
Rainfall	1/5	1/3	1/3	1/2	1/5	1/2	1/2	1	4

Source: {Author's Analysis, (2019)}

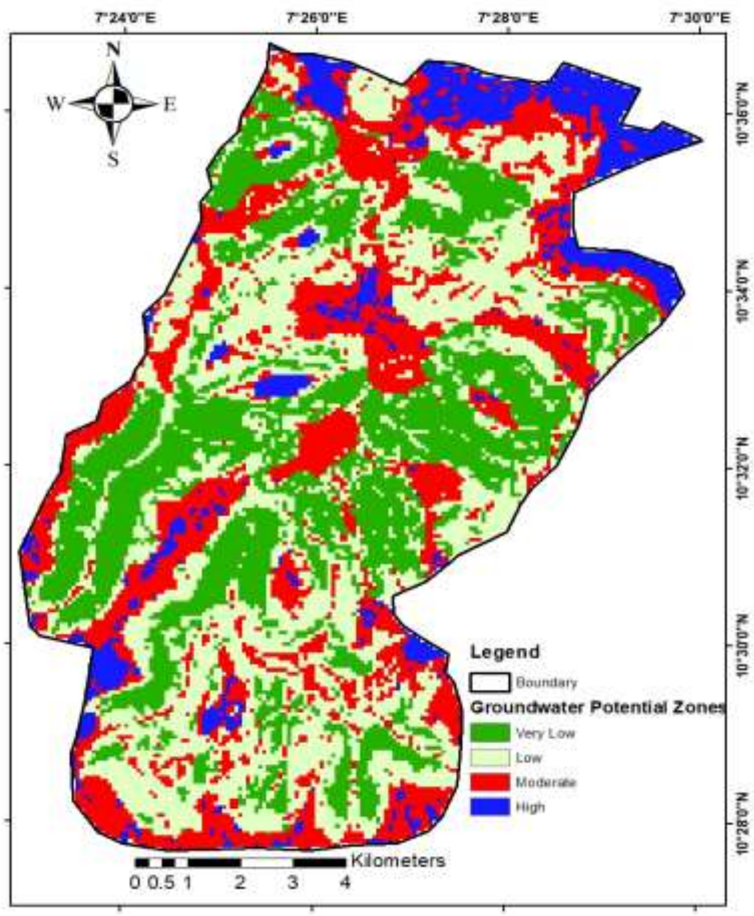

Fig. 10: Groundwater potential map of the study area.

Spatial Extent of the Groundwater Potential Zones

The reclassified groundwater potential map was converted to a shape file in vector format and the calculate geometry tool in ArcGIS 10.4 was used to calculate the area covered by each of the potential zones. The estimated area covered by each potential zone can be seen in Table 10.

Table 10: Areal Coverage of Groundwater Potential Zones

Groundwater Potential Zones	Area in Km^2	Percentage (%)
High	11.43	8.88
Moderate	32.52	25.55
Low	42.52	36.13
Very Low	37.9	29.4
Total	**128.37**	**100**

Source: {Author's Analysis, (2019)}

From Table 4.10 it can be seen that the very low, low, moderate and high groundwater potential zones occupy an area of 37.9 Km^2 (29.4%), 46.52 Km^2 (36.13), 32.52 Km^2 (25.55) and 11.43 Km^2 (8.88%) respectively. The low groundwater potential zone covers 33% of the study area that accounts for 42.52 Km^2 of land area which is the largest of all the delineated potential zones while the high groundwater potential zone coves 8.88% which is the smallest of all the zones. In general, the groundwater potential of the study area can be said to be moderate simply because 35% of the total study area was found to have moderate to high groundwater potential. This can be an explanation for the high rate of borehole failures in the study area.

CONCLUSION

The study successfully delineated the various groundwater potential zones in Kaduna metropolis. It was seen that lineament density, drainage density and elevation were the major groundwater controlling factors in the study area. The northern part of Kaduna metropolis was seen to be the best for ground water exploration. Rainfall doesn't really affect the recharge rate because the metropolis receives enough water to recharge aquifers, this can change should there be a variation in rainfall over time. A study of this nature can help reduce the amount of borehole failures in the study area. It is recommended that the government and other stakeholders should situate projects that are reliant on the availability of water in the northern part of the study area as this area looks to have the best potential for groundwater occurrence. Also a groundwater potential geodatabase should be made for the whole country to enable further studies and development.

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