Applied Journal of Physical Science
Volume 2(3), pages 38-54, August 2020
Article Number: 40E2AD2E1
ISSN: 2756-6684
https://doi.org/10.31248/AJPS2020.028
https://integrityresjournals.org/journal/AJPS

Full Length Research

Modeling of groundwater potential using remotely sensed data within Akure metropolis, Ondo State, Southwestern Nigeria

Ilugbo S. O.[1]*, Adewoye O. E.[2], Aladeboyeje A. I.[2], Magawata U. Z.[3], Oyedele A. A.[4], Alabi T. O.[5], Owolabi D. T.[6], Adeleke K. A.[1] and Adebayo S. O.[1]

[1]Department of Applied Geophysics, Federal University of Technology, Akure, Ondo State, Nigeria.
[2]Department of Physical Sciences, Ondo State University of Science and Technology, Okitipupa, Ondo State, Nigeria.
[3]Department of Physics, Kebbi State University of Science and Technology, Aliero, Nigeria.
[4]Department of Physics, Ekiti State University, Ado Ekiti, Nigeria.
[5]Southwest Drilling, Borehole House, Km 14 Ojoo-Iwo Road Express Way, Ibadan, Oyo State, Nigeria.
[6]Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

*Corresponding author. Email: bussytex4peace44@gmail.com

Received 18th June, 2020; Accepted 27th July, 2020

ABSTRACT: Integrated investigations involving remote sensing and geology have been conducted with the aim of modeling groundwater potential zones within Akure metropolis, Ondo State, Southwestern Nigeria. Groundwater potential zones were delineated with the help of remote sensing and geology. Land sat imageries were used for land use/land cover mapping and lineament analysis for groundwater prospecting. Radar Digital Elevation Model was used for drainage network extraction, slope and geomorphological analysis. All the thematic maps were generated and analyzed in terms of hydrogeological importance and reclassified for integration using ArcGIS 10.5 software. The slope, landuse/landcover, drainage density, lineament density, geomorphology and geological maps generated were integrated with overlay weighted in ArcGIS environment. Suitable ranking and weighting factors were decided based on their capability to store groundwater. This procedure is repeated for all the other layers and resultant layers were reclassified. The groundwater potential zones are classified into five categories of very low, low, moderate, high and very high. The groundwater potential within Akure metropolis is rated as generally low.

Keywords: Akure metropolis, geology, GIS, groundwater potential zones, remotely sensed data.

INTRODUCTION

Groundwater is the water that exists in pore spaces, fractured rock and sediment beneath the Earth's surface (Freeze and Cherry, 1979). The consequences of the surface water inadequacies often lead to water stress in many regions whose main sources of portable water supply is surface water. Water is needed not only for the survival of living things but also to sustain their natural environments (Postel, 1993; Shah et al., 2001; Anderson, 2007). The availability of groundwater depends on various geological factors such as rock types, existence of lineaments and structures suitable for accumulating the resources, hydrological and hydrogeological factors (Ayodele and Odeyemi, 2010; Okereke et al., 2012; Ilugbo and Adebiyi, 2017; Adebo et al., 2018; Ilugbo and Ozegin, 2018). Remote sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas has become a handy tool in assessing and monitoring groundwater resources.

Satellite data provide quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater like lithology/structure, geomorphology, soils, landuse/landcover, lineaments (Ojo et al., 2015). However, all the controlling parameters have rarely been studied together because of non-availability of data, integrating tools and modeling technique. The various thematic layers generated using remote sensing data like lithology/structure, geomorphology, landuse/ landcover, lineaments etc, can be integrated with slope, drainage density and other collateral data in a Geographic Information System (GIS) framework are analysed using a model developed with logical conditions to access groundwater potential (Mukherjee and Das, 1989; Todd and Mays, 2005; Jha et al., 2007; Suja Rose and Krishnan, 2009; Chowdhury et al., 2009; Ilugbo et al., 2018). Assessment of groundwater movement and accumulation based on *in-situ* properties of the subsurface have been carried out (Edet and Okereke, 1997; Ewusi et al., 2009; Lee et al., 2012; Adiat et al., 2013). Therefore, there is a need for finding water in a basement complex environment with little or no reasonable overburden thickness in terms of geology of the environment, and making effort to get water to satisfy the desperate heed of the people within the basement complex region of Akure and it environ. This research focuses on the use of remote sensing data and GIS techniques for evaluating the groundwater potential of Akure metropolis which is underlain by rock of the crystalline Basement Complex of Nigeria.

METHODOLOGY

Site description and geology of the study area

Akure metropolis lies between latitudes $7^{o}\,09^{1}$ and $7^{o}\,19^{1}$N of the equator and longitudes $5^{o}\,07^{1}$ and $5^{o}\,17^{1}$ E of the Greenwich meridian (Figure 1). It covers an area extent of about 340.2 km^2. The metropolis is located on a gently undulating terrain surrounded by isolated hills and inselbergs. Topographic elevations vary between 260 and 470 m above sea level (Owoyemi, 1996; Ojo et al., 2014). The metropolis is drained by several streams and rivers of which is popularly known as Ala River. The study area is part of the Precambrian Basement Complex of Southwestern Nigeria and is underlain by seven geological units (Rahaman 1988). These are the Biotite Gneiss, Charnockite, Granite Gneiss, Migmatite Gneiss, Peltic Schist, Porphyritic Granite and Quartzite (Figure 2).

Method

The method adopted in this study involved base map preparation, digitization, image processing using software and interpretation of the outputs. Remotely sensed data was applied to prepare various thematic maps with reference to groundwater prospect on ArcGIS 10.5 environment. A digital Elevation Model (DEM) downloaded from earth explorer was used to prepare the slope, drainage and geomorphology map. Digital image processing of the satellite data (Landsat TM) was done for geo-referencing and geometric correction. This was followed by the creation of different thematic layers and supervised classification technique was used to produce landuse/landcover. The thematic layers of the extracted features from DEM and satellite imagery including lithology, geomorphology, drainage density, slope, lineaments and landuse/landcover were reclassified in terms of hydrogeological importance. Weightage factors were assigned to themes and their corresponding categories according to the groundwater prospects. The reclassified layers were integrated in a ArcGIS 10.5 environment to produce a composite groundwater potential map of the study area.

RESULTS AND DISCUSSION

Drainage

Drainage density and type of drainage give information related to runoff, infiltration relief and permeability. Dendritic drainage indicates homogenous rocks, the trellis, rectangular and parallel drainage patterns indicate structural and lithological controls (Ilugbo and Adebiyi, 2017). The coarse drainage texture indicates highly porous and permeable rock formations; whereas fine drainage texture is more common in less pervious formations. Figure 3 shows the drainage patterns digitize from topographical map using ArcGIS 10.5. This map consists of water bodies, rivers, tributaries and streams. Major faults, lineaments sometimes connect two or more drainage basins and act as conduits for accumulation of groundwater. Drainage pattern reflects surface characteristics as well as subsurface formation (Horton, 1945). The rose diagram displays a NE-SW and NW-SE trend as the two major drainage orientation directions (Figure 4).

Drainage density

It has been observed from drainage density measurement made over a wide range of geologic and climatic types that low drainage density is more likely to occur in regions of highly permeable subsoil material under dense vegetative cover and low relief (Waikar and Aditya, 2014). High drainage density is the resultant of impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density is representative of coarse drainage texture while high drainage density is typically of fine drainage texture. The drainage density determines the runoff in an area, the quantum of relative rain water that

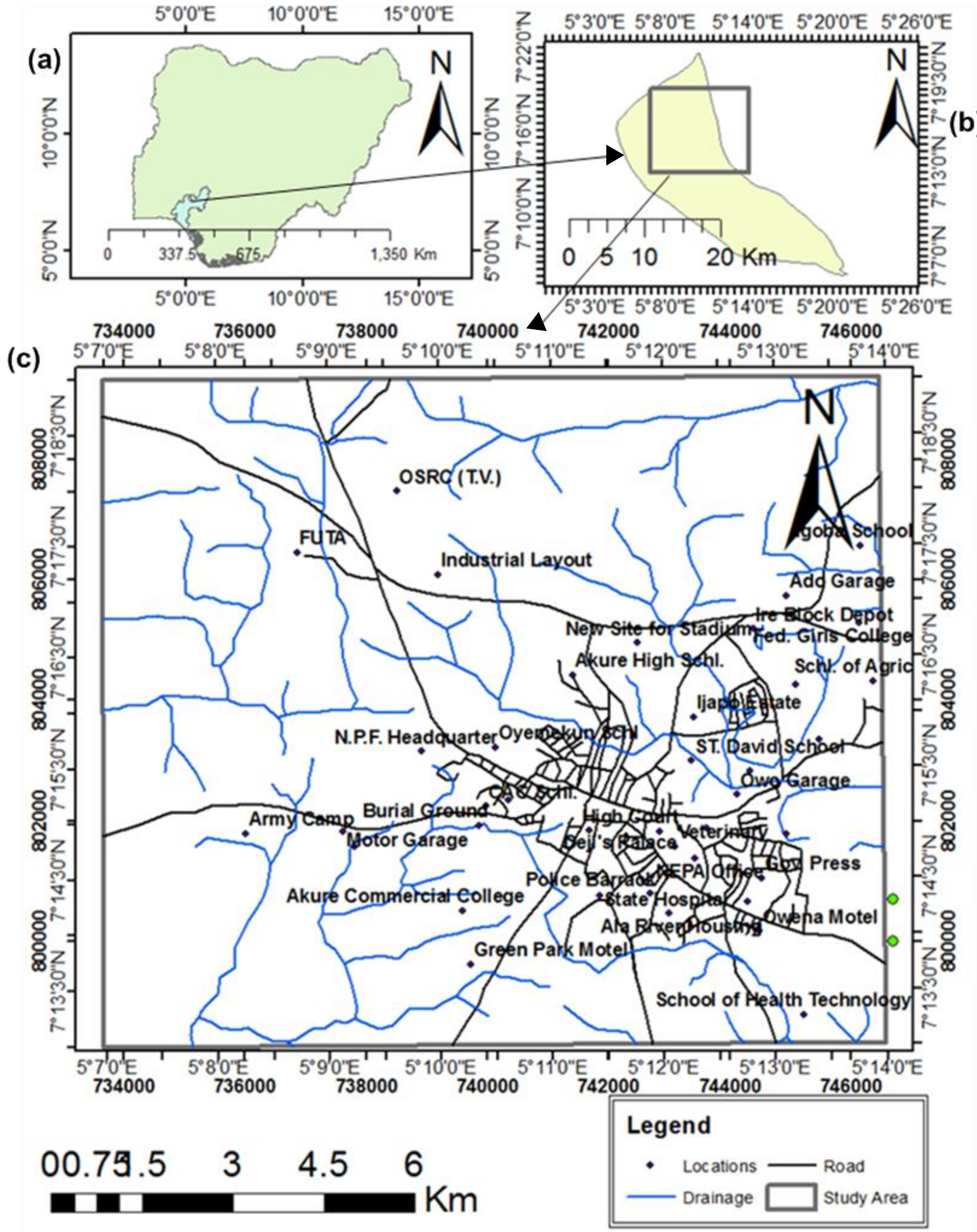

Figure 1. (a) Map of Nigeria showing Ondo State and Akure Metropolis, (b) Map of Akure metropolis showing the location area (c) Location map showing the study area.

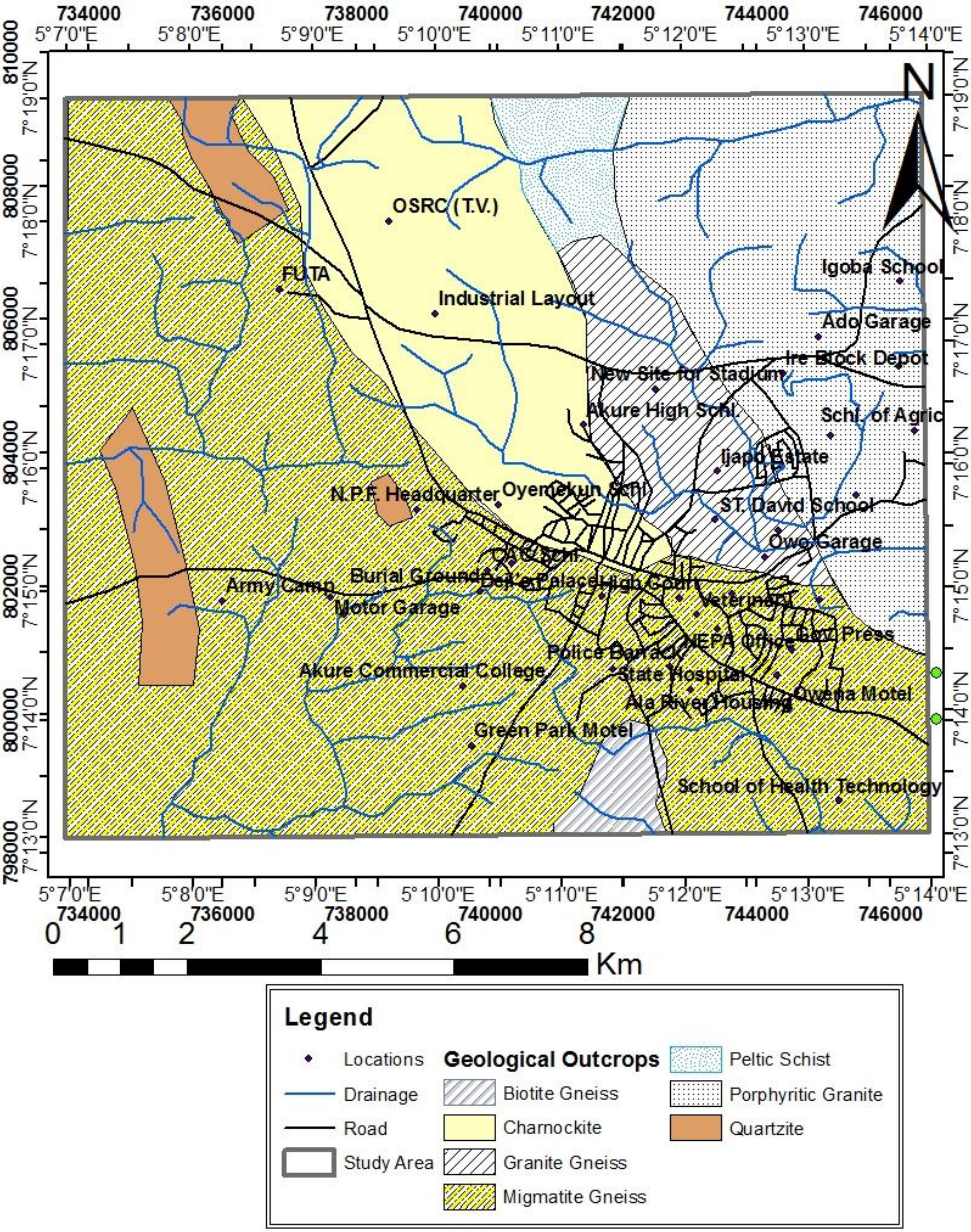

Figure 2. Geology of the Study Area (modified after Owoyemi, 1996).

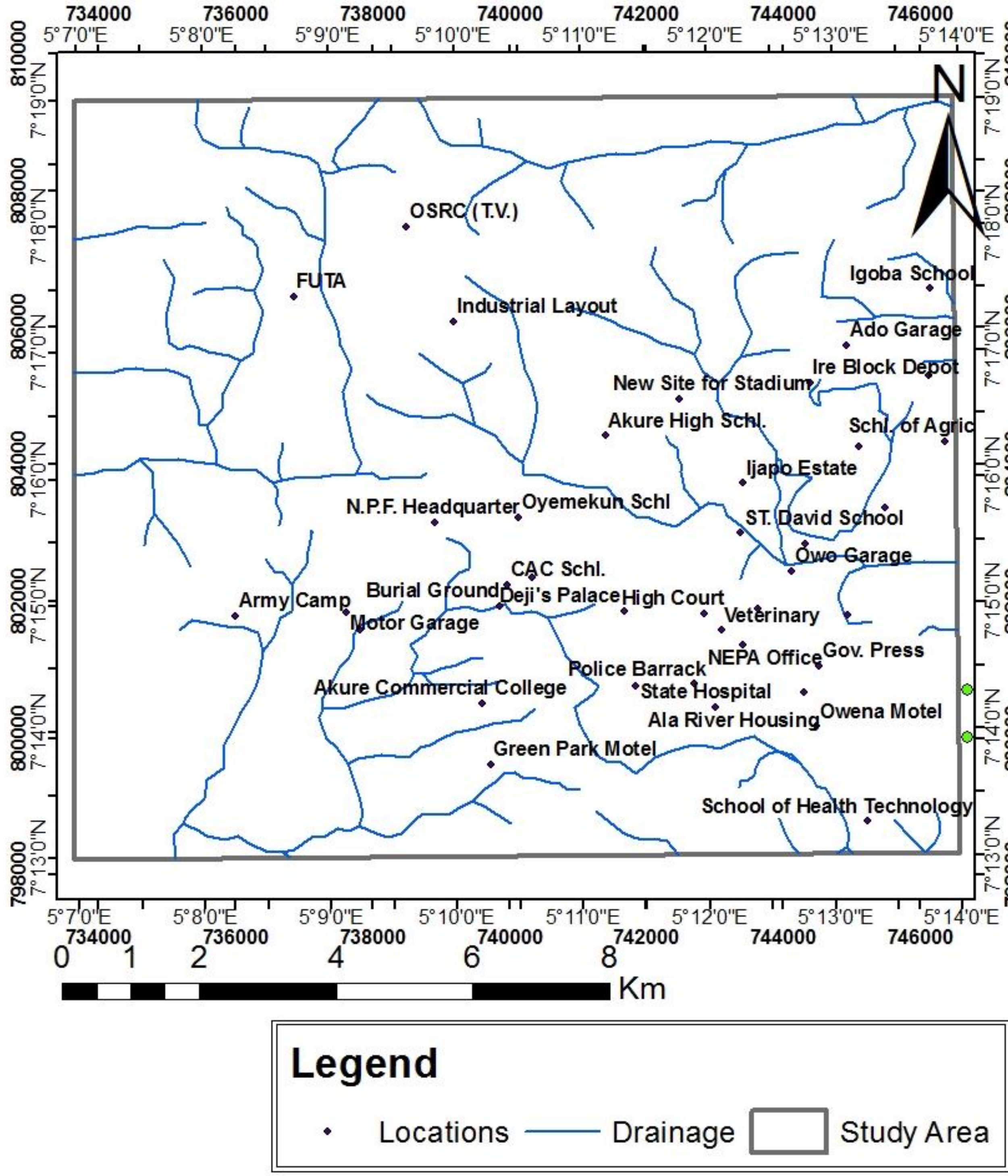

Figure 3. Drainage of the study area.

could have infiltrated. Whereas, the lower the drainage density, the higher the potential for groundwater accumulation. The drainage density map is divided into five categories; very low, low, moderate, high and very high drainage density (Figure 5).

Lineament

The lineaments extracted from satellite image (Landsta TM) as shown in Figure 6 are to demonstrate the usefulness of remote sensing in hydrological

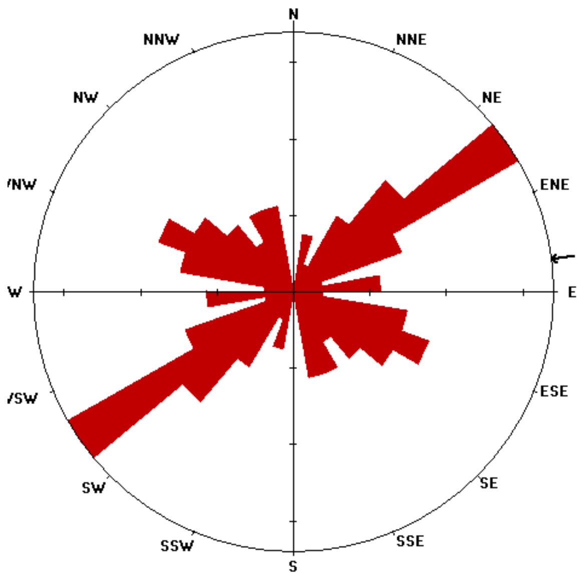

Figure 4. Rose (Azimuth-frequency) diagram of Drainage orientations.

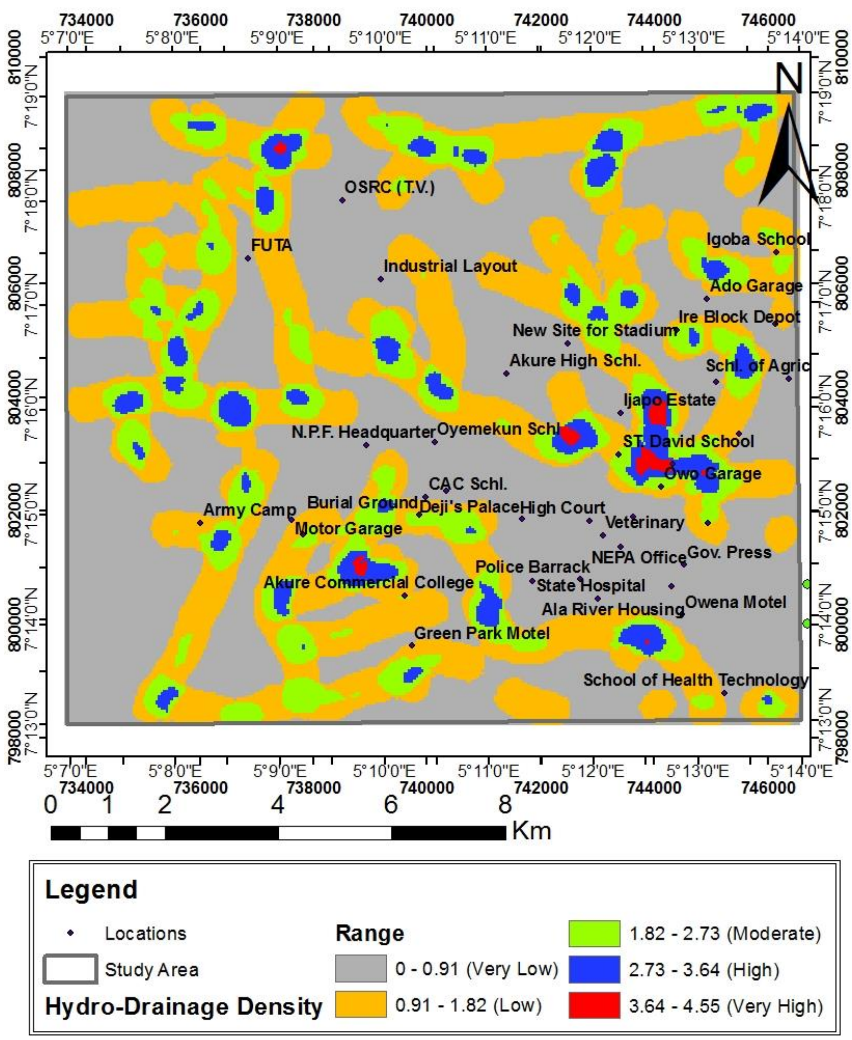

Figure 5. Drainage density of the study area.

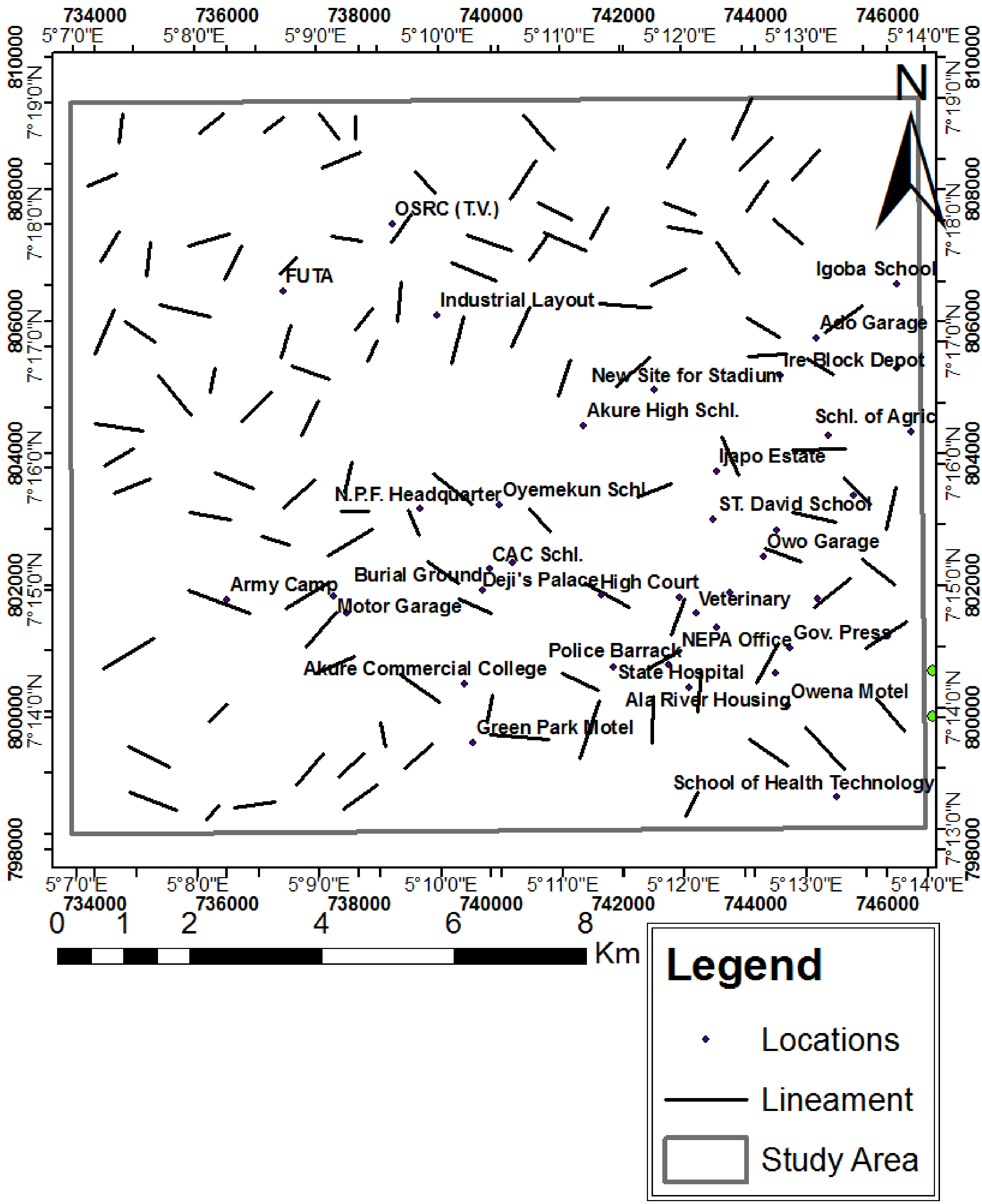

Figure 6. Lineament present in the study area.

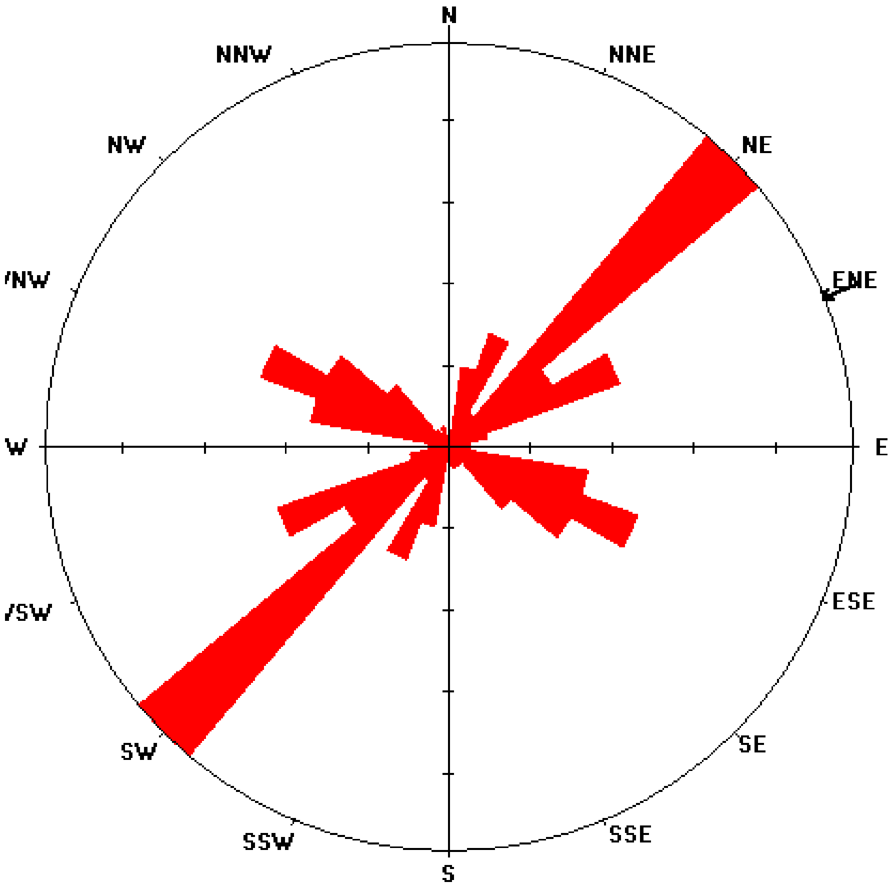

Figure 7. Rose (Azimith-frequency) diagram of lineaments orientations.

investigations most especially in the delineation of zones that are favourable to groundwater development (Ilugbo and Adebiyi, 2017). The map shows that the northwestern part is characterized by very high lineaments; the southeastern part with high lineament. The central part of the study area is characterized by low lineaments while the northeastern and southwestern parts have moderate lineaments. The rose (azimuth-frequency) diagram (Figure 7) prepared from the extracted lineaments from the imagery shows that there was one major lineament trend in the NE-SW direction.

Superimposition of lineaments on drainage pattern

The drainage network map was superimposed on the lineament map (Figure 8) to determine if the drainage system is structurally controlled. The streams do not have an effective intersection with the lineaments (structures) and therefore this will have an effect on the productivity of the groundwater prospect. The map also shows that the streams are not structurally controlled and therefore they are expected to be affected by seasonal variations. The hydrogeological significance and effect of this development arising from an ineffective communications between lineaments and drainage pattern which could recharge aquifer within the study area is significant. Lineaments and drainage pattern play an interdependent role in groundwater development. The study also revealed that the lineaments in the area were constrained to northeast direction while the stream and rivers are flowing nearly northeast and south-western direction, which implies lack of effective communication between the lineaments and drainage

Lineament density

Lineament density is one of the important maps prepared from the lineaments, which are used in groundwater studies in hard rock terrain (Ilugbo and Ozegin, 2018). Areas with high lineament density excluding (the residual hill environment) are favourable for groundwater development (Ilugbo and Adebiyi, 2017). The lineament density map as seen in Figure 9 displays five different lineament density ranges which are summarized in Table 1. The lineament density map shows the prospect for groundwater development in the entire area is generally low.

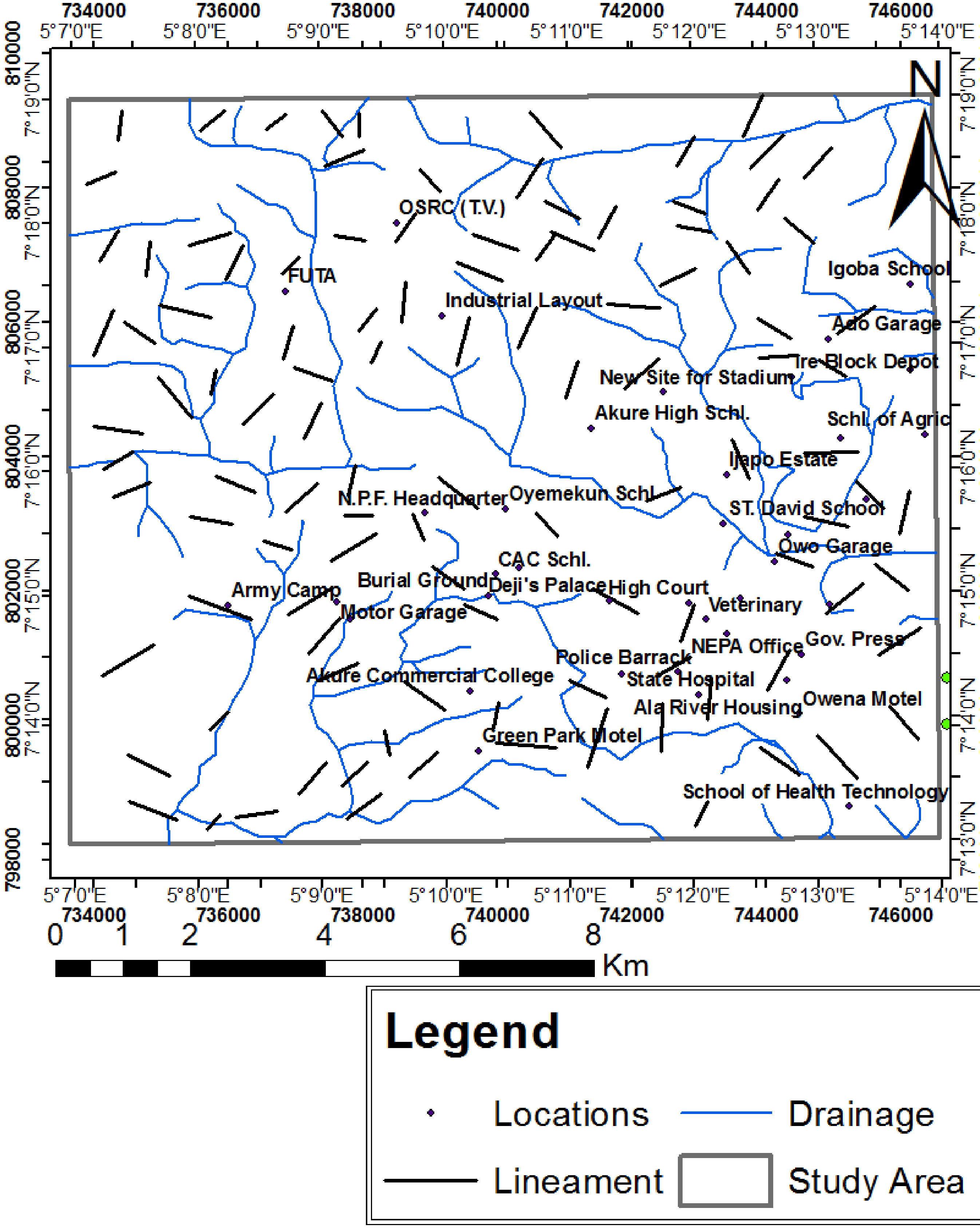

Figure 8. Superimposition of lineament on drainage pattern.

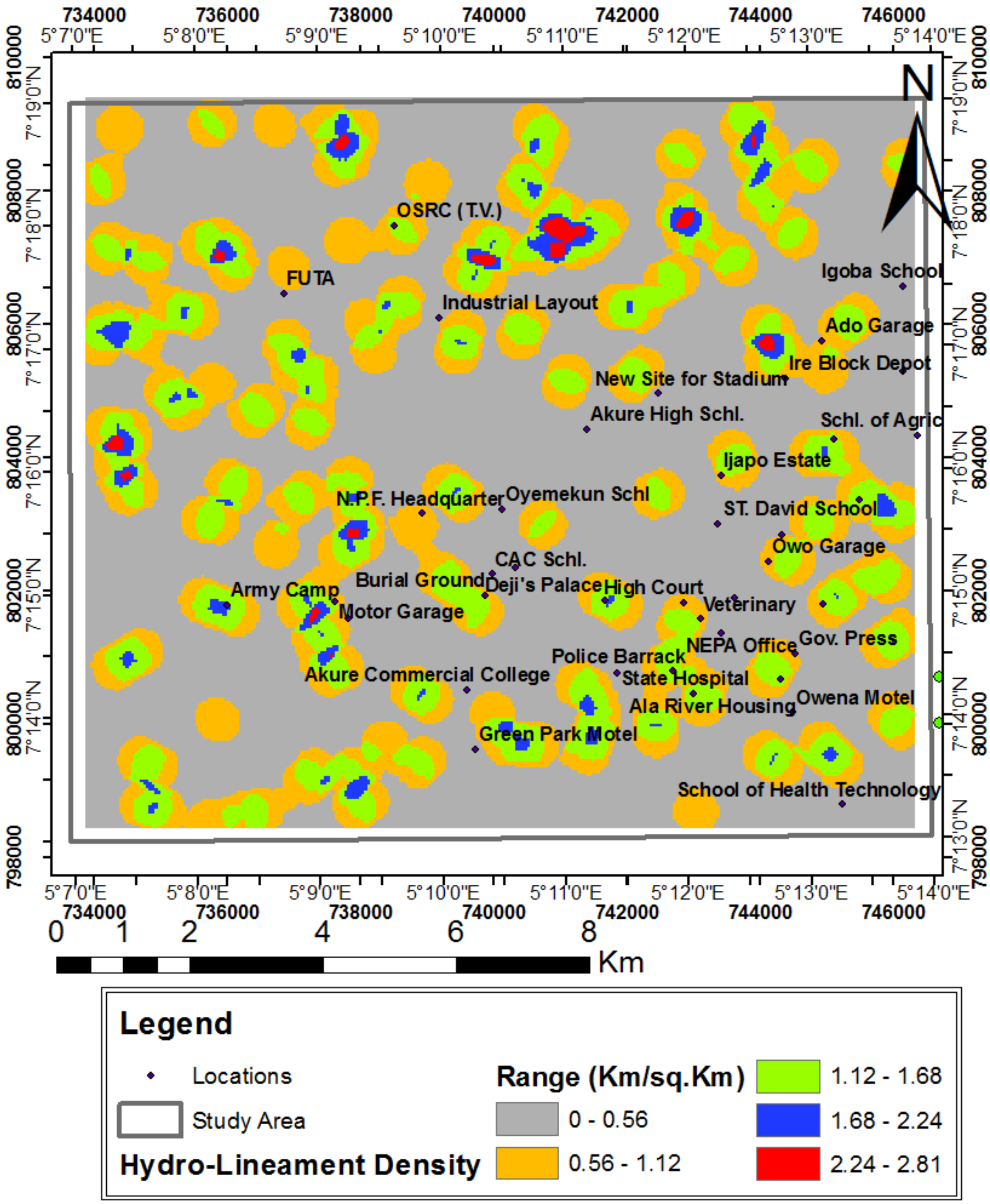

Figure 9. lineament density of the study area.

Table 1. Groundwater prospect of the study area based on lineament density.

Lineaments density range (Km/sq.Km)	Groundwater prospecting
0 – 0.56	Very Low
0.56 – 1.12	Low
1.12 – 1.68	Moderate
1.68 – 2.24	High
2.24 – 2.81	Very High

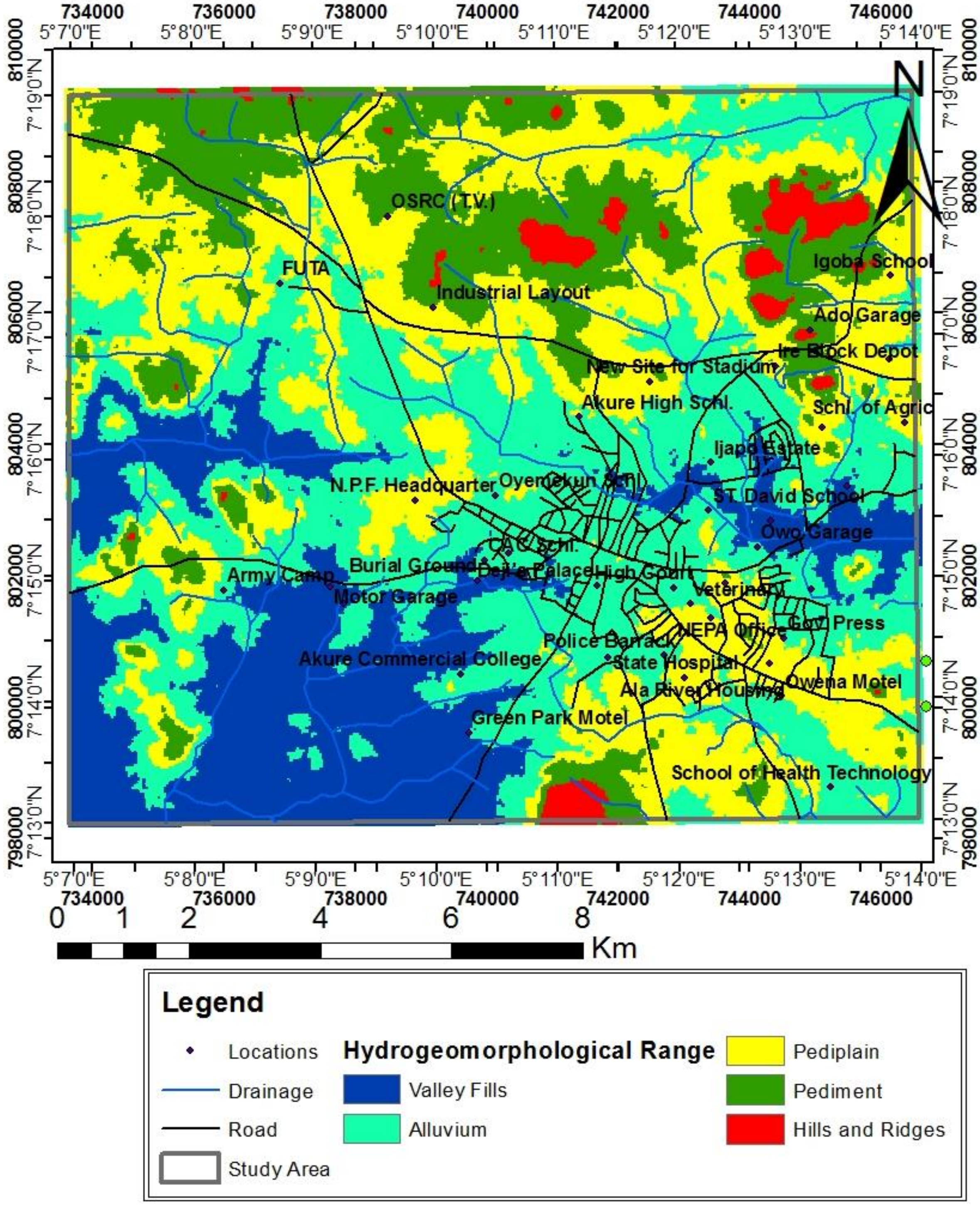

Figure 10. Geomorphology of the study area.

Geomorphology

Geomorphology is the study of the form of the earth, its description and genesis (Gupta, 2003; Waikar and Aditya, 2014). According to the same author, it reflects various land forms and structural features which are favourable for the occurrence of groundwater. The geomorphology of the study area was divided into five categories according to their prospect for groundwater development (Figure 10). These are alluvia, valley fills, pediplain, pediment and hills and ridges of which alluvium and pediplain have good groundwater prospects (Table 2).

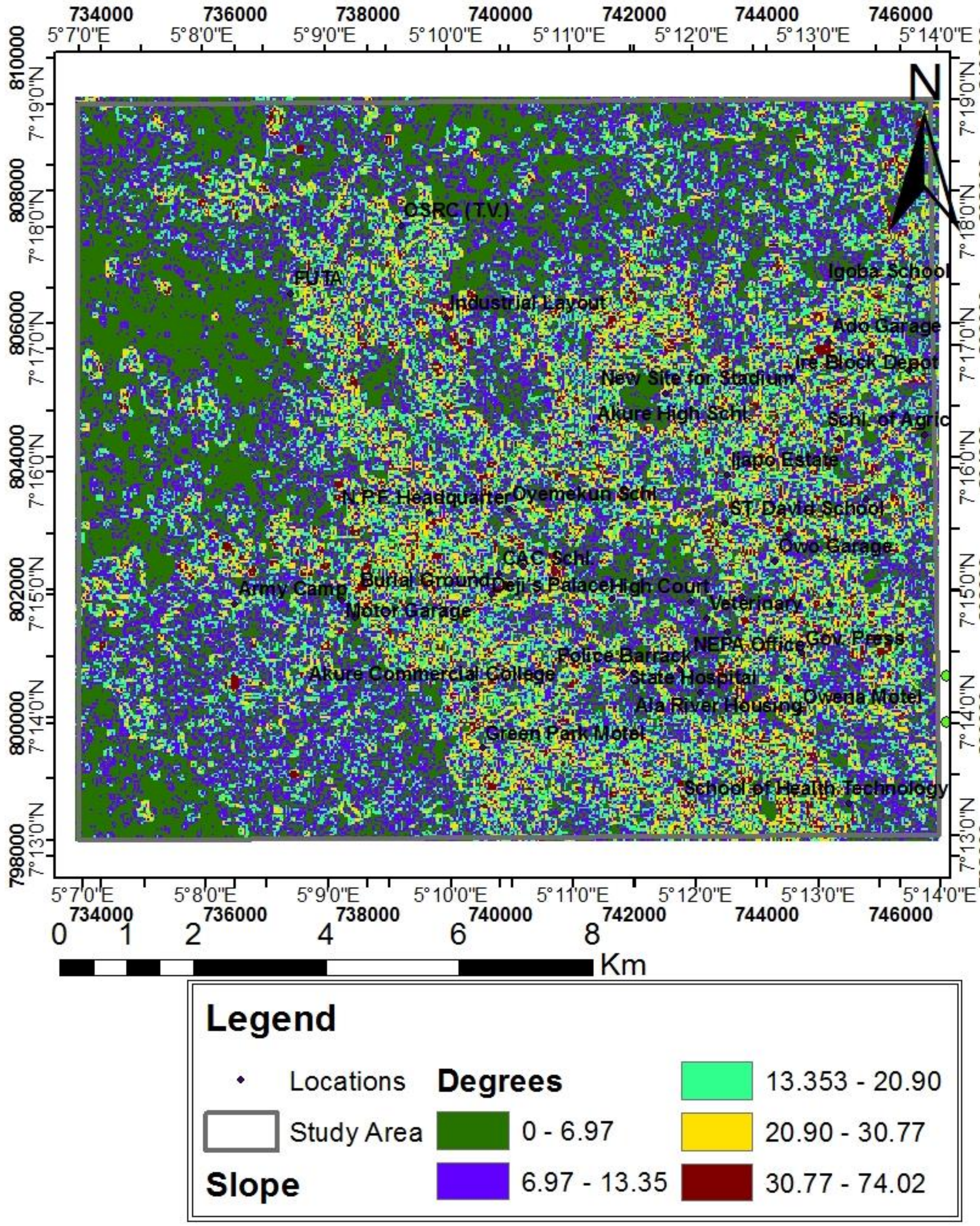

Figure 11. Slope classes of the study area.

Slope

Slope is one of the important terrain parameters which are explained by horizontal spacing of the contours and the elevation raster and measured by the identification of high rate of change in value from each cell to neighboring cells. The slope values in this research were calculated in degrees in both vector and raster forms. Surface gradients ranging from 0° to 74° are observed in the study area (Figure 11) with topographic slope classes of nearly level, very gentle, gentle, moderate, strong, moderately steep to steep and very steep. The groundwater prospect ratings are presented in Table 3.

Land use/land cover

Land use plays a significant role in the evaluation of groundwater resources. The landuse/landcover classes in the study area are vegetation, outcrop, built-up and wetland/water body as shown in Figure 12. In the forest

Table 2. Hydrogeomorphological characterizationof Akure Metropolis (After Srinivasa Rao and Jugran2003; Talabi and Tijani 2011).

Units	Characteristics	Groundwater prospects
Alluvium	Nearly level surface adjoining river courses with intercalations of gravel,coarse–fine sand, clay, etc.	Very good to excellent
Moderately weathered pediplain	Occurring away from hills with gentle slopes and appreciable vegetationcover. The potentials are increased when underlain by fractures withincreased weathered zone thickness	Good to very good
Shallow weathered pediplain	Gentle to medium slope with sparse vegetation; possess only mediumgroundwater prospect unless when underlain by fractures	Medium to good
Inselberg,residual hill and denudational hill	characterized by medium to high relief/steep slopes with varying areaextent or dimensions	Poor
The valley fills	Consist of weathered materials and in-filling of unconsolidated materialsin the valley areas; usually underlain by fractures	Very good

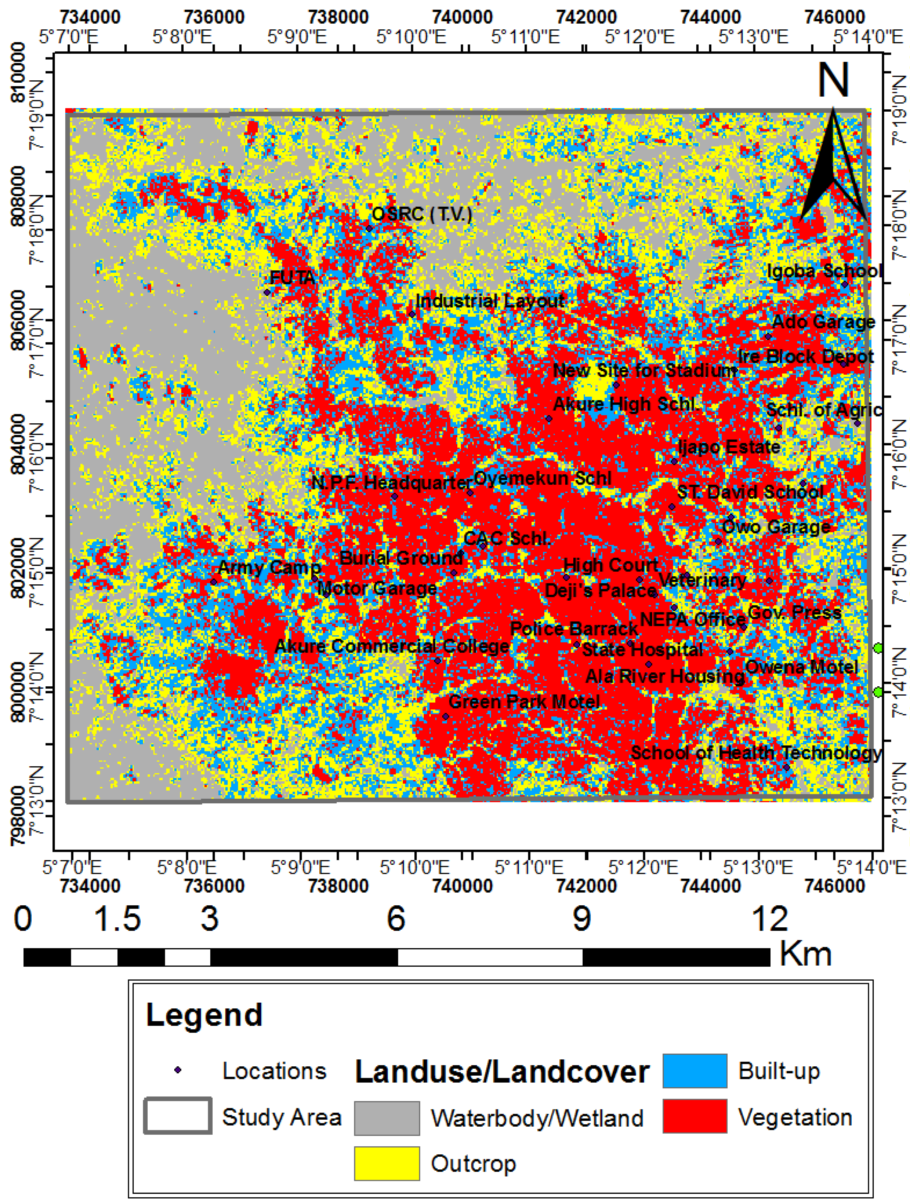

Figure 12. Land use/land cover classes of the study area.

Table 3. Classification of slope in the study area.

Classes (Degrees)	Attributes	Groundwater pProspect
0 – 6.67	Gently sloping	Very high
6.97 – 13.35	Moderately sloping	High
13.35 – 20.90	Moderate steep sloping	Moderate
20.90 – 30.77	Steep sloping	Low
30.77 – 74.02	Very steeply sloping	Very Low

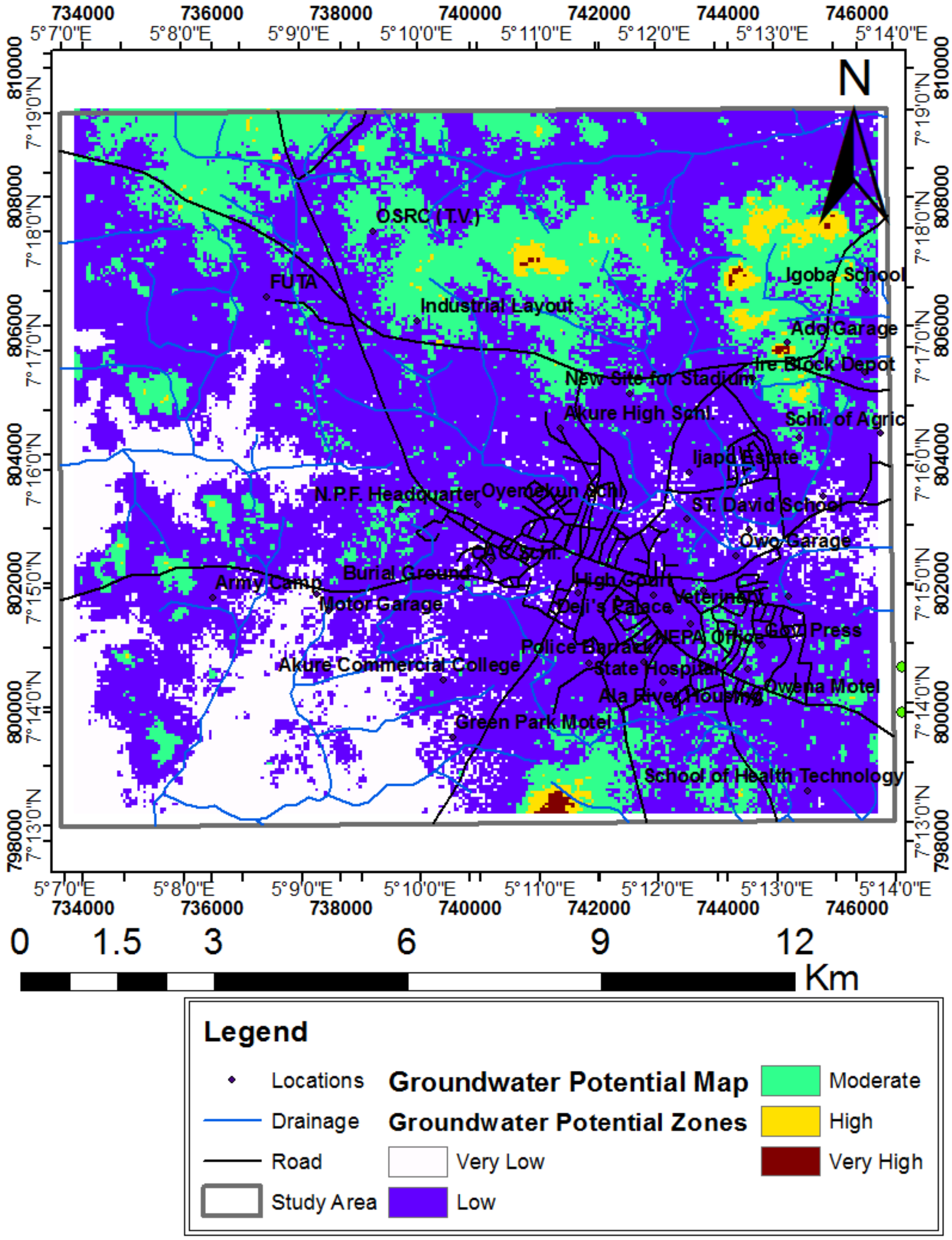

Figure 13. Groundwater potential map of the study area.

Table 4. Probability rating (R) for classes of the parameters.

Influencing Factors	Category (Classes)	Potentiality for Groundwater Storage	Rating (R)	Normalized Weight (W)
Lineament Density	0 – 0.56	Very Low	1	20
	0.56 – 1.12	Low	2	
	1.12 – 1.68	Moderate	3	
	1.68 – 2.24	High	4	
	2.24 – 2.81	Very High	5	
Drainage density	0 – 0.91	Very Low	1	15
	0.92 – 1.82	Low	2	
	1.82 – 2.73	Moderate	3	
	2.73 - 3.64	High	4	
	3.64 – 4.55	Very High	5	
Geomorphology		Valley fills	5	15
		Alluvium	4	
		Pediplain	3	
		Pediment	2	
		Hill and ridges	1	
Slope	0 – 6.67	Gently sloping	5	15
	6.97 – 13.35	Moderately sloping	4	
	13.35 – 20.90	Moderate steep sloping	3	
	20.90 – 30.77	Steep sloping	2	
	30.77 – 74.02	Very steeply sloping	1	
Landuse/landcover		Vegetation	5	15
		Built-up area	3	
		Outcrop	3	
		Wetland/waterbody	1	
Geology		Biotite Gneiss	3	20
		Charnockite	1	
		Granite gneiss	3	
		Migmatite gneiss	2	
		Pelticschist	3	
		Porphyritic granite	3	
		Quartzite	5	

areas, infiltration will be more and runoff will be less whereas in urban areas rate of infiltration may decrease. The built-up areas would have low water-holding capacity unlike the wetland/water bodies and cultivated lands that have high water-holding capacity.

Groundwater potential modeling

The groundwater potential zones were obtained by overlaying the thematic maps using the weighted overlay method of the spatial analysis tool in ArcGIS 10.5. During the weighted overlay analysis in ArcGIS environment, the ranks have been given for each individual parameter of each thematic map and the weight is assigned according to their potentiality for groundwater storage (Table 4). The spatial analysis and modeling involve integration of lineament density, drainage density, geomorphology, slope, landuse/landcover and geology thematic layers. Weights ranging from 1 to 5 were assigned to the classes with respect to groundwater prospect in ascending order. The thematic maps were synthesized in a GIS environment using weighted indices for groundwater potential map development (Figure 13). The groundwater potential map classified the study area into very low, low, moderate, high and very high groundwater potential zones.

Conclusion

Geographical information system and remote sensing data has proved to be powerful and cost effective method for determining groundwater potential in parts of Akure metropolis. The study revealed that drainage density, slope, geology, geomorphology, lineament density and land use/land cover give information on areas suitable for groundwater exploration. The given study area is classified into very high, high, moderate, low and very low groundwater potential zones. This groundwater potential information will be useful for effective identification of suitable locations for extraction of water. Remote sensing–GIS approach would serve as the preliminary inventory method to understand groundwater potential index and facilitate delineation of zones adjudged suitable for further groundwater investigations.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCE

Adebo, A. B., Ilugbo, S. O. and Oladetan, F. E. (2018). Modeling of Groundwater Potential UsingVertical Electrical Sounding (VES) and Multi-caterial Analysis at Omitogun HousingEstate, Akure, Southwestern Nigeria. *Asian Journal of Advanced Research and Reports*, 1(2), 1-11.

Adiat, K. A. N., Nawawi, M. N. M., & Abdullah, K. (2013). Application of multi-criteria decision analysis to geoelectric and geologic parameters for spatial prediction of groundwater resources potential and aquifer evaluation. *Pure and Applied Geophysics*, 170(3), 453-471.

Anderson, M. P. (2007). Introducing groundwater physics. *In: The studies of the physics of water beneath Earth's surface the basis of groundwater hydrology*. Physic Today. American Institute of Physics. Pp. 45-67.

Ayodele, O. S., & Odeyemi, I. B. (2010). Analysis of the lineaments extracted from LANDSAT TM image of the area around Okemesi, SouthWestern Nigeria. *Indian Journal of Science and Technology*, 4(1), 31-36.

Chowdhury, A., Jha, M. K., Chowdary, V. M., & Mal, B.C. (2009). Integrated remote sensingand GIS-based approach for assessing groundwater. *International Journal of Remote Sensing*, 30(1), 231-250.

Edet, A. E., & Okereke, C. S. (1997). Assessment of hydrogeological conditions in basement aquifers of the Precambrian Oban massif, southeastern Nigeria. *Journal of Applied Geophysics*, 36(4), 195-204.

Ewusi, A., Kuma, J. S., & Voigt, H. J. (2009). Utility of the 2-D multi-electrode resistivity imaging technique in groundwater exploration in the Voltaian sedimentary basin, Northern Ghana. *Natural resources research*, 18(4), 267-275.

Freeze, R. A., & Cherry, J. A. (1979). Groundwater. Prentice-Hall, Englewood. Cliffs Fitts CR (2002) Groundwater science. Academic, San Diego.

Gupta, R. P. (2003). Remote sensing geology. 2nd edition, Springer, Berlin, Germany, Pp. 460-477.

Horton, R. E., (1945). Erosional development of streams and their drainage density: hydrophysical approach to quantitative geomorphology. *Bulletin of the Geological Society of America,* 56, 2 75-3 70.

Ilugbo, S. O, Adebo, B. A, Olomo, K. O., & Adebiyi A. D. (2018). (2018). Application of GIS and multi-criteria decision analysis to geoelectric parameters for modeling of groundwater potential around Ilesha, Southwestern Nigeria. *European Journal of Academic Essays*, 5(5), 105-123.

Ilugbo, S. O., & Adebiyi, A. D. (2017). Intersection of lineaments for groundwater prospect analysis using satellite remotely sensed and aeromagnetic dataset around Ibodi, Southwestern Nigeria. *International Journal of Physical Sciences*, 12(23), 329-353.

Ilugbo, S. O., & Ozegin, K. O. (2018). Significances of deep seated lineament in groundwater, studies around Ilesha, Southwestern Nigeria., *Asian Journal of Geological Research*, 1(1), 1-16.

Jha, M. K., Chowdhury, A., Chowdary, V. M., & Peiffer, S. (2007). Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. *Water Resources Management*, 21(2), 427-467.

Lee, S., Song, K. Y., Kim, Y., & Park, I. (2012b). Regional groundwater productivity potential mapping using a geographic information system (GIS) based artificial neural network model. *Hydrogeology Journal*, 20(8), 1511-1527.

Okereke, C. N., Onu, N. N., Ibe, K. K., Selemo, A. O. I., Opara, A. I., Ikoro, D. O., Ibeneme, S. I., & Oha, I. A. (2012). Analysis of landsat and aeromagnetic data for mapping of linear structures: a case study of Yola area, Upper Benue Trough, Nigeria. *International Journal of Engineering Research and Applications*, *2*, 1968-1977.

Ojo, J. S., Olorunfemi, M. O., Bayode, S., Akintorinwa, O. J., Omosuyi, G. O., & Akinluyi, F. O. (2014). Constraint map for landfill site selection in Akure metropolis, Southwestern Nigeria. *Ife Journal of Science*,16(2), 205-416.

Ojo, J. S., Olorunfemi, M. O., Akintorinwa, O. J., Bayode, S., Omosuyi, G. O., & Akinluyi, F. O. (2015). GIS integrated geomorphological, geological and geoelectrical assessment of the groundwater potential of Akure Metropolis, southwest Nigeria. *Journal of Earth Sciences and Geotechnical Engineering*, 5(14), 85-101.

Postel, S. (1993). Water and agriculture. In: Gleick, P.H. (ed). *Water in crisis: A guide to the world's fresh water resources*. Oxford University Press, New York, Pp. 56-66.

Rahaman, M. A. (1988). Recent advances in the study of the Basement Complex of Nigeria. In: Oluyide, P. O., Mbonu, W. C, Ogezi, A. E., Egbuniwe, I. G., Ajibade, A. C., & Umeji, A.C. (eds.). *Precambrian Geology of Nigeria*. Geological Survey of Nigeria Special Publication, Pp. 11-41.

Srinivasa Rao, Y., & Jugran, D. K. (2003). Delineation of groundwater potential zones and zones of groundwater quality suitable for domestic purposes using remote sensing and GIS. *Hydrological Sciences Journal*, 48(5), 821-833.

Shah, T., Molden, D., Sakthivadivel, R., & Seckler, D. (2001). Global groundwater situation: Opportunities and challenges. *Economic and Political Weekly*, 36(43), 4142-4150.

Suja Rose, R. S., & Krishnan, N. (2009). Spatial analysis of groundwater potential using remote sensing and GIS in the Kanyakumari and Nambiyar basins, India. *Journal of the Indian Society of Remote Sensing*, 37(4), 681-692.

Talabi, A. O., & Tijani, M. N. (2011). Integrated remote sensing and GIS approach to groundwater potential assessment in the basement terrain of Ekiti area southwestern Nigeria. *RMZ Mater Geoenviron*, 58(3), 303-328.

Todd, D. K., & Mays, L. W. (2005). Groundwater hydrology. Wiley, New York.

Waikar, M. L., & Aditya, P. N. (2014). Identification of groundwater potential zone using remote sensing and GIS technique. *International Journal of Innovative Research in Science, Engineering and Technology,* 3(5), 12163-12174.