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Groundwater Exploration Within Shallow Depths Around Distinct Litho-Petrological Contact Zones

E. G. Ejiga [1, *], A. Nur [2], N. C. Izuwa [3] and O. Olabode [3]

[1] Department of Physics, College of Science & Technology, Covenant University, Ota, Nigeria.
[2] Department of Geology, Faculty of Physical Sciences, Modibbo Adama University, Yola, Nigeria.
[3] Department of Petroleum Engineering, College of Engineering, Covenant University, Ota, Nigeria.

eko.ejiga@covenantuniversity.edu.ng; http://orcid.org/0000-0003-4874-9806
anur@mau.edu.ng
nkemakolam.izuwa@futo.edu.ng; http://orcid.org/0000-0001-8084-3275
oluwasanmi.olabode@covenantuniversity.edu.ng; http://orcid.org/0000-0002-0538-7385

Corresponding email: eko.ejiga@covenantuniversity.edu.ng

Abstract. The world's increasing demand for freshwater has put a strain on existing reserves in recent years, necessitating further exploration of new groundwater reserves. However, geologic provinces located within the contact boundary of Sedimentary Basin-Basement Complex region are somewhat faced with the problem of shallow sediment thickness. As a result, exploring for groundwater poses a challenge as the sediment thickness might be insufficient to host productive aquifers. Hence, exploring for faults and fractures zones that are embedded on the hard rock underneath the sediment is very essential and complimentary. In this study, high resolution aeromagnetic data over a litho-petrological contact zone of the Middle Benue Trough (MBT) and the Adamawa Massif were analyzed to delineate groundwater exploration areas using a simplified qualitative and quantitative approach. Visual inspection of isolated and aggregate anomalies is performed by analyzing their shapes, dimensions, lateral extents, and discontinuities. Lineaments were then extracted from the residual magnetic map to determine faults, fractures, and joints. A two-source-depth model is indicated by the Spectral Analysis technique used to determine the thickness of the sediments in the area. The deeper source (Z_1) has a thickness of 0.9 - 3.6 km, while the shallow source (Z_2) has a thickness of 0.1 - 0.8 km. While in some areas the overburden thickness may be sufficient for groundwater exploration, in others it was not, as indicated by the shallow magnetic depth, Z_2. Nonetheless, areas of shallow thickness but with aggregates of faults, fractures, and joints were identified as possible locations for groundwater accumulation through magnetic lineament exploration.

Keywords: Groundwater; Lineaments; Magnetic anomaly; Spectral analysis; Sediment thickness; Aquifer; Benue Trough.

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1. Introduction

Groundwater is now the preferred alternative water source because of the pressing need to find additional freshwater resources to meet the increasing demand. Rapid population growth, the expansion of industry or agriculture, the deterioration of surface water quality, and environmental degradation due to global warming are the major causes of this rising demand. In order to identify high yielding aquifers, groundwater investigation techniques must be applied and used properly due to the high cost of drilling boreholes [1]. On the other hand, groundwater resource exploration benefits greatly from the use of various geophysical methods like magnetic, electrical and electromagnetic methods either used alone or in conjunction with other traditional geophysical methods [2-5]. The development of various geophysical techniques and equipment to aid in exploration activities. has been prompted by this global demand for groundwater, which has been growing in the recent past. While some of these techniques are complex and require the use of sophisticated interpretational software, others utilize a simple and qualitative approach. All these are geared towards increasing the sensitivity and accuracy in detection and mapping of concealed structures hosting this groundwater resources. Of all the geophysical prospecting techniques, the magnetic method is the most flexible, and its maps can display a wide range of local anomalies. Currently, faults, fractures, basement topography, and characterization as well as sediment thickness estimation for groundwater and oil and gas exploration are mapped using the magnetic method [5-8]. Mapping the hydrogeological environments where water can exist is the primary objective of geophysical investigation in groundwater exploration. Areas with shallow sediment thicknesses similarly with hard rock environments contain fractures, joints, and fault zones that are formed by various tectonic or chemical processes. These features are typically used to store and transport groundwater. The majority of the groundwater resources are located in a weathering grade that is halfway between fresh bedrock and worn rock. The hydrogeological properties of the weathered bedrock are determined by the weathering processes. In addition to other hydrogeological and geological parameters, the thickness of the sediment/weathered and fractured rocks covering the fresh bedrock determines the groundwater potential in most environments. Because weathered/fracture zones in hard rocks offer preferred water flow pathways, their identification and characterization are critical to groundwater productivity [4, 9]. In hard rock, the aquifer's thickness is not constant and changes depending on the level of weathering and erosion [10]. The assessment of groundwater potential in both soft and hard rock areas has been aided by the identification of weak magnetic anomalies originating from sedimentary rocks, such as

IOP Conf. Series: Earth and Environmental Science **1342** (2024) 012040 doi:10.1088/1755-1315/1342/1/012040

sandstone faulting, as well as the appraisal of potential fracture and fault zones [11]. Areas with a high concentration of short-wavelength magnetic anomalies are often dominated by geologic features, such as faults, fractures, fissures, dyke swamps, etc. [6, 12].

Nigeria has a rapidly growing population exceedingly over 200 million which pose a lot of pressure on the water resource management and utilization. This paper presents a simple and fast reconnaissance survey for groundwater exploration in litho-petrological contact zone often characterize by shallow sediment thickness like the Adamawa Massif and the Middle Benue Trough (MBT) of Nigeria.

2. Study Location and Geologic Setting

The study area lies between latitudes 7^0 00' N and 8^0 00' N, and longitudes 9^0 00' E and 10^0 00' E. It encompasses approximately 12,100 km2 of farmland, settlement, natural reserves, privately owned farms, and towns. The study area's geology is made up of two distinct major petrological groups namely, the Basement Complex rocks (Hard rocks) and the Sedimentary rocks (Soft rocks). The hard rocks include the Migmatite Gneiss Complex and the Older Granite, while the soft rocks include the Asu River Group, Ezeaku Formation, and Quaternary alluvium (Figure 1). Banded gneiss, granite gneiss, and porhyroblastic gneiss dominate the migmatite gneisses complex. Biotite granite with medium to coarse grains makes up the older granites. The Asu River group is mainly shale and limestone with sandstone intercalation. Ezeaku formation is made up of sandstone. The study area's northwest section is a part of The Benue Trough, a NE-SW trending linearly rifted graben basin. The basin’s development is linked to the Early Cretaceous period, when the African and South American continents split apart. The Trough is filled with sediments ranging in age from Cretaceous to Recent, and it is surrounded by an elevated basement block on either sides [13, 14].

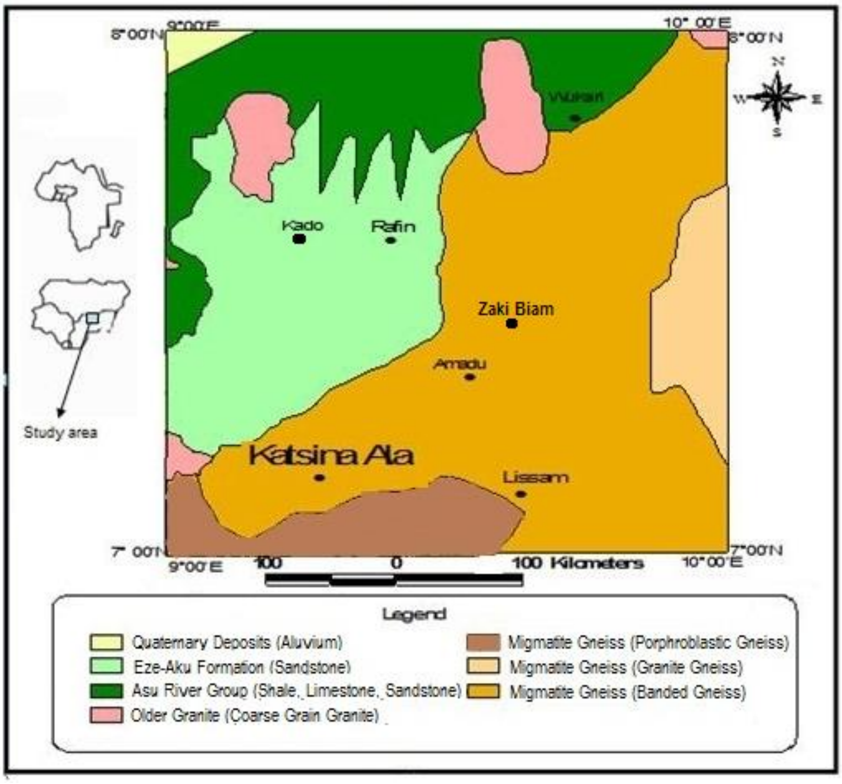

Figure 1: Geological Map of the Study Area. After. [15]

3. Material and Methods

The three major phases of this research were data collection, data processing, and data interpretation. Geophysical concepts and interpretation, however, would serve as a guide for both qualitative and quantitative analyses, which are elements of the interpretation of magnetic data. For this work, the high resolution aeromagnetic map (HRAM) covering some petrological contact zones within the Adamawa Massif adjacent to the Nigerian Middle Benue Trough was used (Figure 2a). The Nigerian Geological Survey Agency (NGSA) which provided the aeromagnetic data had between 2005 and 2009 acquired some digital air-geophysical data for the entire country. The TMI was subjected to a Regional-Residual separation technique using Oasis Montaj software to yield the Residual magnetic anomaly map (Figure 2b).

Examining the forms and patterns of the main anomalies visually is the first step in the qualitative analysis of a magnetic anomaly map. Following the identification of the structural trends, each unique anomaly's distinguishing characteristics are examined in more detail. The

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early stages of the study are dominated by this process, which is primarily map-based. It includes providing amplitude, width, and trend description of the anomaly. On the other hand, the quantitative process starts with the drawing of lines on maps to identify lineaments as well as finding the depth values that correspond to the thicknesses of the sediments. The depth estimation process was executed through spectral depth analysis technique. Sixty-four (64) blocks totaling 13.75 km x 13.75 km were created from the residual data of the study area in order to perform the Spectral analysis for depth determination. The analysis was carried out using Oasis Montaj.

The formula for calculating depth to magnetic sources from the slope of the spectral graph, which was modified from Spector and Grant [16], was used to determine the average depth to magnetic sources for each of the sixty-four blocks. Assuming that Z represents the layer's mean depth, exponent ($-2Zk$) can be used to serve as this magnetic ensemble's depth factor. Therefore, a straight line with a slope of $-2Z$ is obtained when the logarithmic plot of the radial spectrum versus the frequency is plotted (Figure 3).

Consequently, the average depth of the ensemble can be found from

$$Z = \frac{-S}{4\pi} \tag{1}$$

where the frequency is given in cycles per kilometer and S represents the slope of the best fitting straight line.

Equation 1 was used to determine the average depths to magnetic sources for each of the sixty-four blocks by analyzing the graphs' slopes. The plots depict series of points which is represented by one or more straight lines corresponding to the slopes which is related to the depths. The slope section of the higher frequency range is attributed to shallow magnetic sources while the lower frequencies are from the deeper sources. The two linear segments are represented by the two lines on the graph in Figure 3.

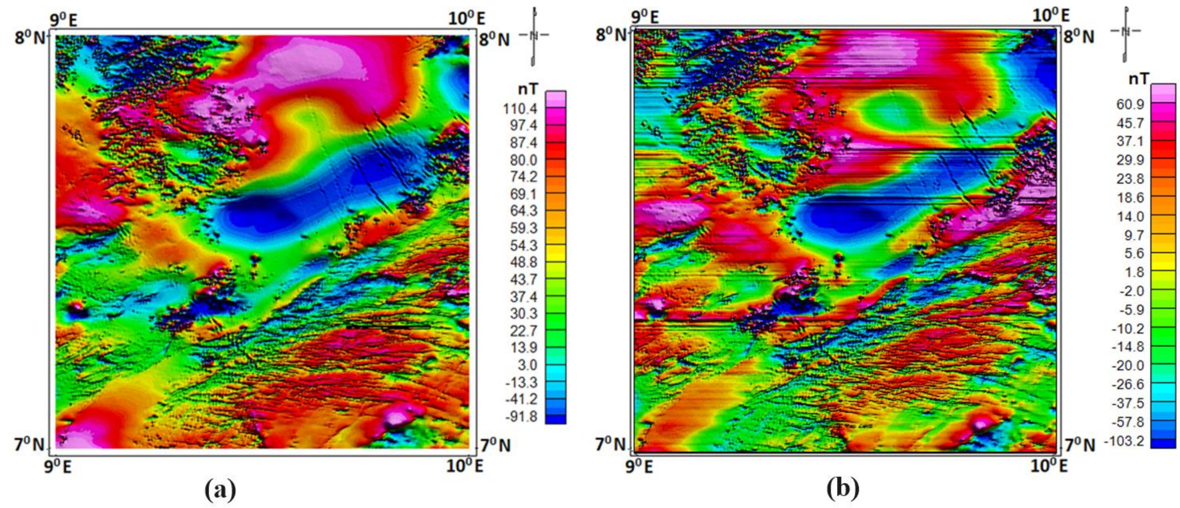

Figure 2: (a) Total Magnetic Intensity (TMI) map of the study area. (b) Residual Magnetic map.

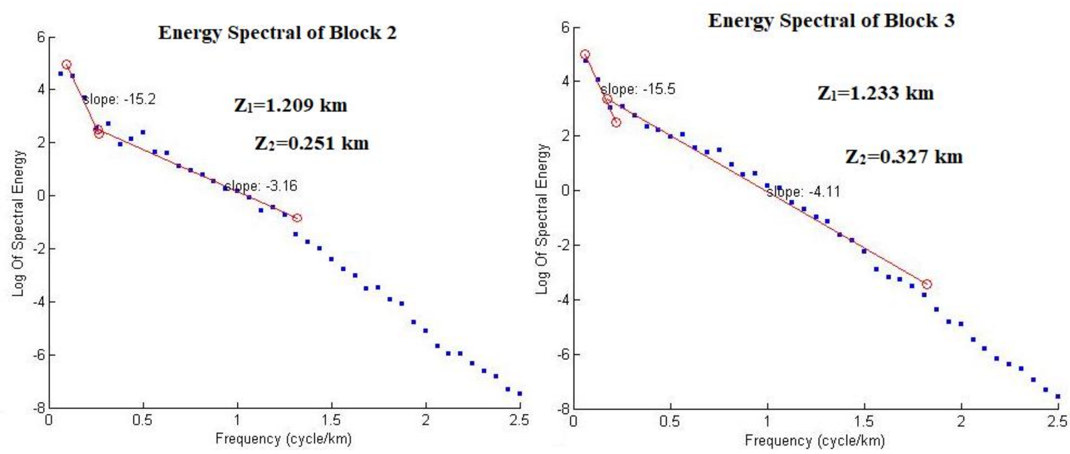

Figure 3. Graphs of spectral energies for Block 2 and 3. (Z_1 represent the deep magnetic source while Z_2 represent top of intra-sedimentary magnetic sources).

4. Results and Discussion

The values of Z_1 denote the deep magnetic sources which can be attributed to the top of the basement, while the values Z_2 represent depth to top of shallow magnetic sources which are

IOP Conf. Series: Earth and Environmental Science **1342** (2024) 012040 doi:10.1088/1755-1315/1342/1/012040

intra-sedimentary intrusions, as presented in Table 1. The depth values for the shallow magnetic source, Z_2 ranges from 0.174 km to 0.685 km with an average of 0.38 km. It can be observed that the topography of the surface of Z_2 is undulating (Figure 4) and most likely have been affected by the serious of intrusive volcanic activities documented to have taken place within the MBT [6, 7, 17, 18].

Table 1: Average depth (km) to magnetic sources across the study area computed from spectral analysis.

BLOCK1 Z_1 =0.363	**BLOCK2** Z_1=1.209 Z_2=0.251	**BLOCK3** Z_1=1.233 Z_2=0.327	**BLOCK4** Z_1=1.011 Z_2=0.449	**BLOCK5** Z_1=3.119 Z_2=0.563	**BLOCK6** Z_1=2.347 Z_2=0.629	**BLOCK7** Z_1=1.003 Z_2=0.496	**BLOCK8** Z_1=1.042 Z_2=0.354
BLOCK9 Z_1=0.696 Z_2=0.282	**BLOCK10** Z_1=0.987 Z_2=0.329	**BLOCK11** Z_1=1.011 Z_2=0.377	**BLOCK12** Z_1=0.995 Z_2=0.208	**BLOCK13** Z_1=3.055 Z_2=0.638	**BLOCK14** Z_1=1.719 Z_2=0.630	**BLOCK15** Z_1=1.758 Z_2=0.395	**BLOCK16** Z_1=1.050 Z_2=0.477
BLOCK17 Z_1=0.804 Z_2=0.400	**BLOCK18** Z_1=1.082 Z_2=0.291	**BLOCK19** Z_1=1.583 Z_2=0.215	**BLOCK20** Z_1=1.384 Z_2=0.325	**BLOCK21** Z_1=1.488 Z_2=0.331	**BLOCK22** Z_1=1.265 Z_2=0.505	**BLOCK23** Z_1=1.233 Z_2=0.469	**BLOCK24** Z_1=1.090 Z_2=0.312
BLOCK25 Z_1=1.727 Z_2=0.403	**BLOCK26** Z_1=1.361 Z_2=0.174	**BLOCK27** Z_1=1.265 Z_2=0.296	**BLOCK28** Z_1=3.159 Z_2=0.387	**BLOCK29** Z_1=2.204 Z_2=0.685	**BLOCK30** Z_1=1.981 Z_2=0.294	**BLOCK31** Z_1=2.164 Z_2=0.337	**BLOCK32** Z_1=0.409
BLOCK33 Z_1=1.074 Z_2=0.290	**BLOCK34** Z_1=1.090 Z_2=0.426	**BLOCK35** Z_1=1.209 Z_2=0.355	**BLOCK36** Z_1=1.074 Z_2=0.344	**BLOCK37** Z_1=1.416 Z_2=0.407	**BLOCK38** Z_1=0.962 Z_2=0.398	**BLOCK39** Z_1=0.827 Z_2=0.388	**BLOCK40** Z_1=0.931 Z_2=0.396
BLOCK41 Z_1=0.644 Z_2=0.447	**BLOCK42** Z_1=0.995 Z_2=O.320	**BLOCK43** Z_1=0.843 Z_2=0.422	**BLOCK44** Z_1=0.915 Z_2=0.454	**BLOCK45** Z_1=1.098 Z_2=0.397	**BLOCK46** Z_1=0.963 Z_2=0.290	**BLOCK47** Z_1=0.947 Z_2=0.329	**BLOCK48** Z_1=0.790 Z_2=0.373
BLOCK49 Z_1=0.674 Z_2=O.369	**BLOCK50** Z_1=1.066 Z_2=0.396	**BLOCK51** Z_1=0.454	**BLOCK52** Z_1=0.383	**BLOCK53** Z_1=0.931 Z_2=0.329	**BLOCK54** Z_1=0.851 Z_2=0.313	**BLOCK55** Z_1=0.730 Z_2=0.317	**BLOCK56** Z_1=1.361 Z_2=0.407
BLOCK57 Z_1=1.337 Z_2=0.401	**BLOCK58** Z_1=0.704 Z_2=0.398	**BLOCK59** Z_1=0.820 Z_2=0.364	**BLOCK60** Z_1=1.249 Z_2=0.364	**BLOCK61** Z_1=0.644 Z_2=0.362	**BLOCK62** Z_1=0.979 Z_2=0.317	**BLOCK63** Z_1=0.947 Z_2=0.380	**BLOCK64** Z_1=0.835 Z_2=0.387

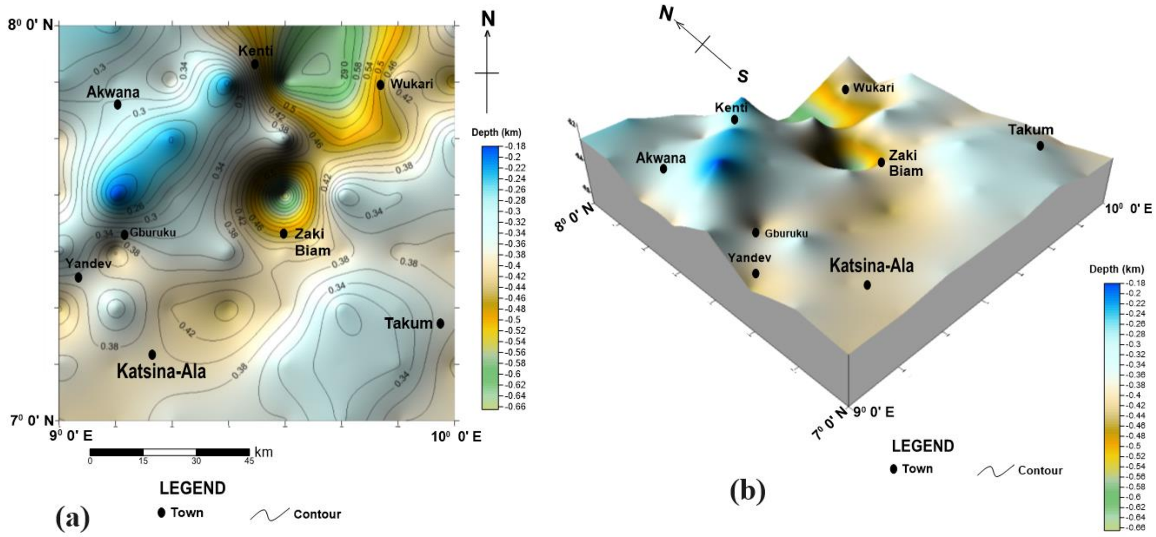

Figure 4: (a) Top view of the shallow magnetic surface. (b) Top-side view

The depth values (Z_1 & Z_2) derived from the spectral analysis technique correspond to the hard rock below the sediments. This is due to the fact that sedimentary rocks in a sedimentary basin exhibit very little magnetic susceptibility in comparison to igneous or metamorphic rocks. As a result, it is believed that the hard rocks beneath the sediments correspond to the magnetic field strength measured from the Earth's surface [7, 19]. Therefore, all magnetic responses can be ascribed to the underlying hard rocks, with the exception of the very short wavelength. The mapped lineaments/fractures are thought to be embedded beneath the sediments, on top of the shallowest hard rocks. As a result, the shallow magnetic depth (Z_2) represents depths to these fractures and as well as represents the depth to the top of the shallowest magnetic sources in different blocks. For instance, in areas where the depth model is from a single magnetic source, such as Blocks 1, 32, 51, and 52, Z_2 coincides with the top of the basement as well as the top of the intra-sedimentary intrusions. However, in areas with a two-source depth model, such as Blocks 2, 3, 4, 5, and so on, Z_2 represents the depth to the top of intra-sedimentary features, while Z_1 represents the depth to the top of the basement.

Due to the oxidation of magnetite to hematite or the infilling of fracture planes by dyke-like bodies whose magnetic susceptibilities differ from those of their host rocks, there will typically always be a magnetic susceptibility contrast across a fracture zone. On an aeromagnetic map, these geologic features can show up as nosing or thin elliptical closures. prominent elliptical closures or nosing of contours whose directions and orientation are similar to the elongation of the contours were identified as geologic lineaments (Figure 5). High density of fractures identified in areas around Akwana, Kenti, Zaki Biam Yandev, Takum and Tor Donga are potential sites for groundwater explorations. These fractures and faults serve as pathways for groundwater accumulation where the sediment thickness is insufficient to host productive aquifers especially in the basement complex, terrain. Depths of up to 0.5km and above are dominant in the northern parts like Kenti, Wukari and the central part like Zaki Biam. These correspond to areas of thick sedimentary cover and are potential sites for groundwater exploration as well. Other areas with good prospect for groundwater are western parts like Yandev and Gburuku. The prominent fractures and joints trend NE-SW with minor fractures trending NW-SE direction (Figure 6). On a regional scale, these lineament trends correspond to the pre-pan African and pan-African deformational episodes. It might also be connected to those that originated in previously established weak zones, which coincide with Africa's main tectonic zones [20].

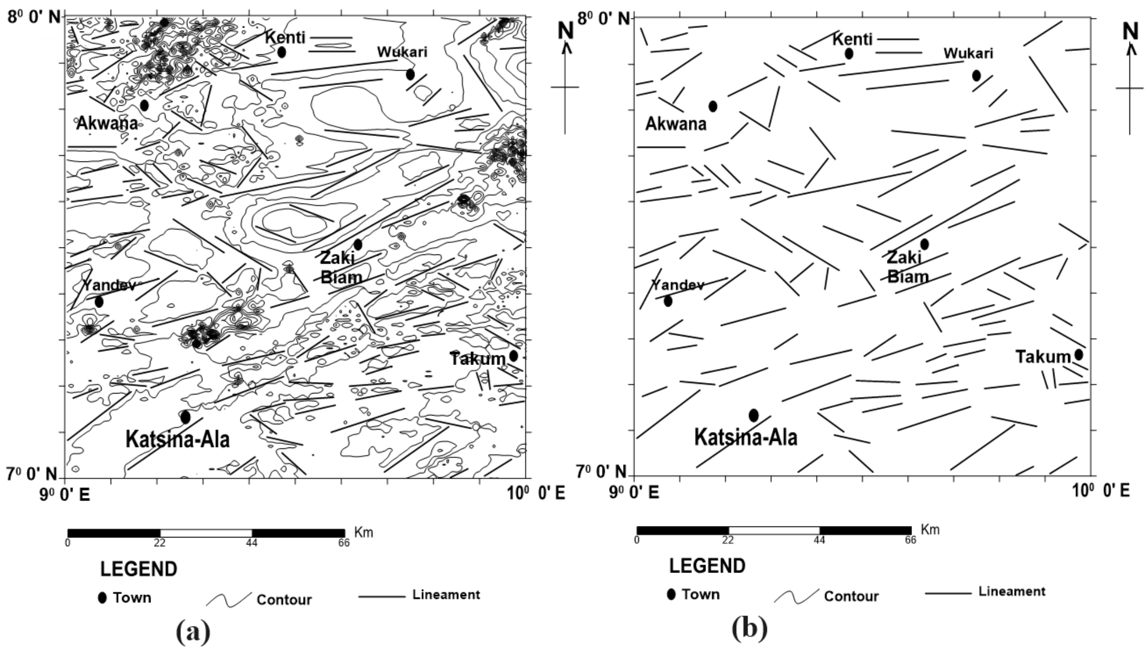

Figure 5: (a) Residual magnetic lineaments map with anomaly contours (Interval of 40nT). (b) Lineament map of the study area

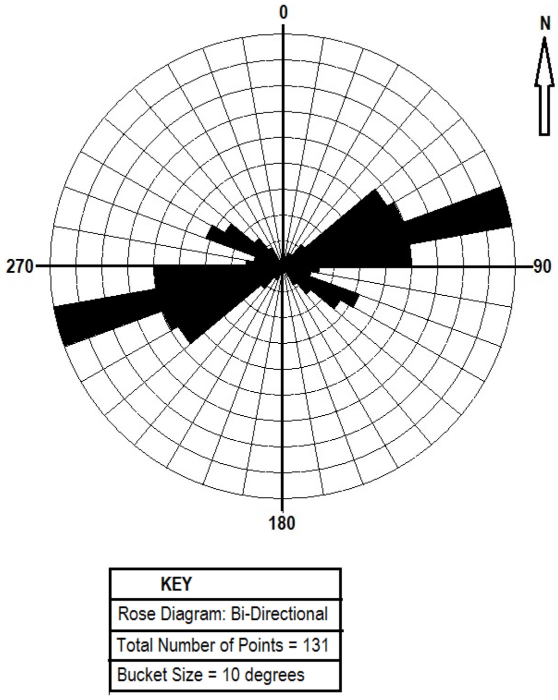

Figure 6: Rose diagram showing the orientation of lineaments in the study area.

5. Conclusion

Shallow sediment thickness is a problem in geologic provinces located within a contact boundary of the Sedimentary-basement region, particularly within the contact zone. Exploring for groundwater is difficult because the sediment thickness may be insufficient to support productive aquifers. Exploration for faults and fracture zones embedded on the hard rock beneath the sediment is therefore critical and complementary. As a result of estimating the thickness of the sediment and delineating the lineaments in the area, more insight into the subsurface framework of the study area has been provided, which can serve as a platform for further exploratory work on a regional scale. The relatively high sediment thicknesses in some areas provide the suitability to host aquifer which are good indicators of groundwater potentials. However, areas where the overburden thickness might not be sufficient but having aggregates of fractures are also considered as good locations for groundwater exploration. The major structural trends in the area are NE-SW, with minor trends extending in the direction of NW-SE and E-W. This aligns with the Benue Trough of Nigeria's regional structural framework.

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