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Full Length Research

Regional groundwater studies using high-resolution aeromagnetic data in Abuja and environs, North-Central Nigeria

James Ejike Ebele* and Ahmed Nur

Department of Geology, School of Physical Science, Modibbo Adama University of Technology P.M.B. 2076, Yola, Adamawa State, Nigeria.

*Corresponding author. Email: jamesejikeebele@gmail.com; Tel: +2348038052763.

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ABSTRACT: Abuja and environs usually experiences water shortage during the dry season as a result of rapid population growth, due to the fact that the water from Lower Usuma Dam used for domestic and industrial purposes are no longer sufficient to cater for its teeming population. The shortage can be minimized through better understanding of lineament configurations of the area. Regional groundwater studies using high-resolution aeromagnetic data in Abuja and environs, North-Central Nigeria were carried out to address water shortages in Abuja and its surroundings. The aim of the study was to identify groundwater targets/potential zones for the purpose of providing sufficient water to the communities in the area. The study area is situated in the North-Central part of Nigeria and lies between latitudes 8° 00'- 9°30' N and longitudes 6°30'- 8°00' E. First vertical derivative (1VD) technique was applied to the residual magnetic data of the study area using Oasis Montaj software version 8.3 and thereafter extracted lineaments from 1VD map using ArcGIS software version 10.4.1. Result of 1VD technique indicates that polyphase deformation was pervasive throughout the area as joints, fractures, faults, as well as folds in the map. Major lineament trends identified in the study area are NNE-SSW 27.47%, NE-SW 25.54%, ENE-WSW 18% and N-S 9.57%, the magnitudes and orientations of the lineaments are essential for groundwater movement. The study indicates that Dogon-Kurmi, Gitata, Rafin, Gurku, Karshi, Keffi, Paiko, Farindoki, Takuti, Lambata, Izom, Tudun Wada, Safon Lapai, Mayaki, Gwagwalada, Gidan Ali, Takura, Dafa, Dangara, Abaji, Kwali, Zuba, Madalla, Gauraka, Suleja, Kuje, Abuja, Bwari, Udegi, Zango-Daji, eastern part of Katakwa, Gadabuke, Buga, Koton-Karfe, Bibirako, Kworaki, Toto, Dagoshi and Umaisha have good groundwater prospect. Fieldwork conducted in the area confirmed the existence of lineaments/fractures in the area and as such are targets for groundwater exploration.

Keywords: First vertical derivative, groundwater potential zones, high resolution aeromagnetic data, lineaments, Nigeria.

INTRODUCTION

In the last two decades, Federal Capital Territory (FCT) Abuja and environs have experienced rapid growth in population due to influx of people in search of greener pastures (Adeeko and Ajala, 2015; Akpan et al., 2018; Abdullahi et al., 2019; Obiadi et al., 2019). Due to this rapid population growth, the water from Lower Usuma Dam used for domestic and industrial purposes are no longer sufficient to cater for its teeming population in the area (Idris-Nda et al., 2015; Adeeko et al., 2017; Chup and Iyanya, 2017; Kasidi, 2017; Ismaila, 2018; Omotoso and Akanbi, 2018). The region usually experiences water shortage during the dry seasons, but the shortage can be minimized through better understanding of lineament configurations of the area (Dan-Hassan et al., 2016; ohiambe et al., 2019). The study area was aimed at applying high-resolution aeromagnetic data analysis and interpretation to delineate areas of groundwater potential.

Gudmundsson (2011) stated that fluid flow in rocks within the crust occurs through pores and fractures (lineaments). According to National Research Council

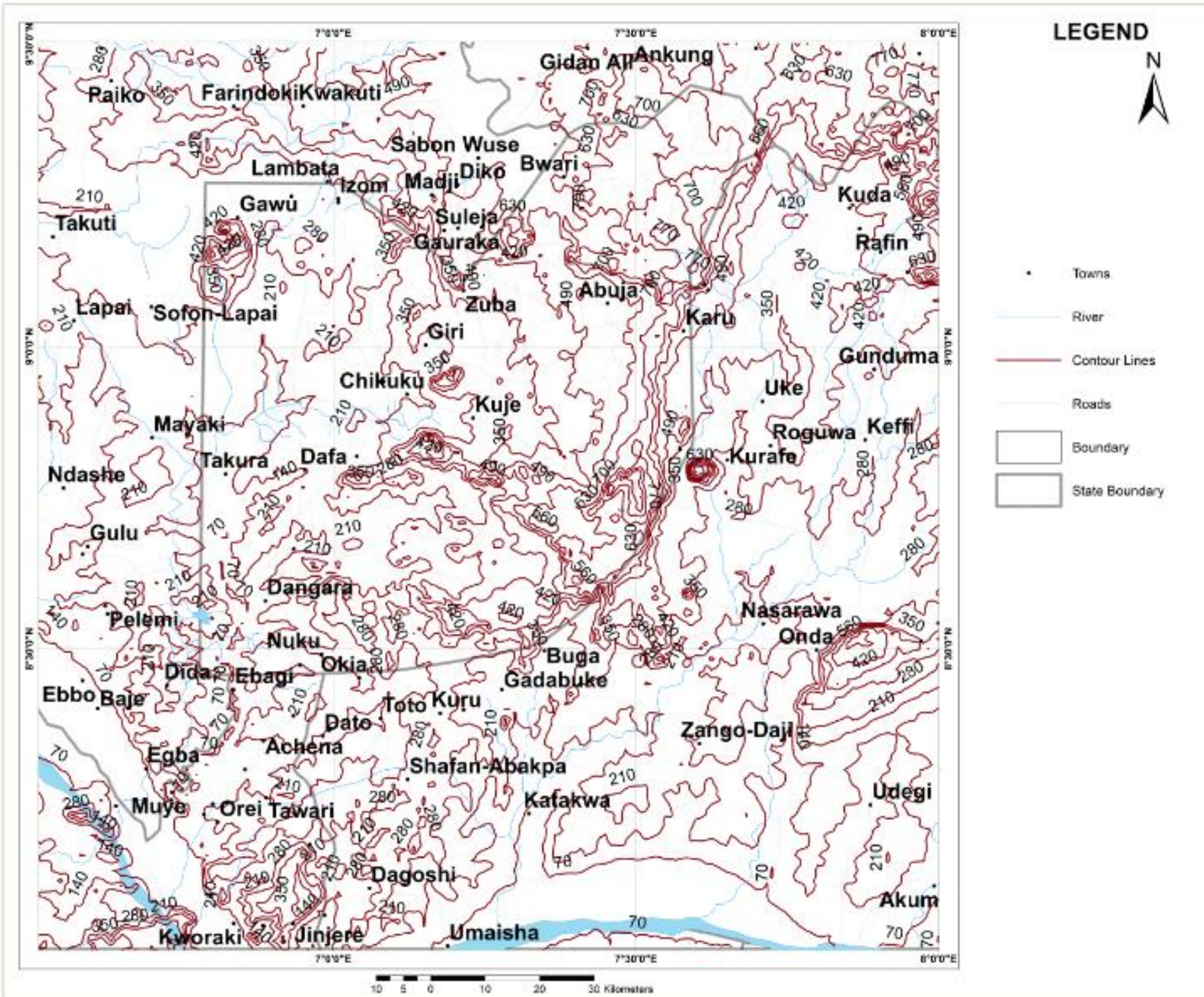


Figure 1. Topographic map of the study area (After National Space Research and Development Agency-NASRDA, 2014).

(1996), fractures (lineaments) serve as hydraulic conductors and also provide pathways for fluid flows. In basement terrains, geological structures such as lineaments are the main controlling factor to groundwater movement. Lineaments play an important role in groundwater exploration particularly in basement complex areas due to the fact that they act as zones of groundwater recharge (Fernandes and Rudolph, 2001; Hung et al., 2003; Kim, 2004). Several studies indicate that regional groundwater flows are controlled by major faults (Mayer and Sharp, 1998; Ferrill et al., 1999). The relationship between lineaments, groundwater flows and yields have been described by several authors (Lattman and Parizek, 1964; Mabee et al., 1994; Magowe and Carr, 1999; Fernandes and Rudolph, 2001; Hung et al., 2003). Conventional techniques utilised in lineament evaluation includes frequency or length against azimuth histograms (Mostafa and Zakir, 1996), rose-diagrams (Nalbant and Alptekin, 1995), and lineament density maps (Zakir et al., 1999). Additionally, spatial distributions of lineaments are also characterised by studying lineament density and intersection density of lineaments (Kumar and Reddy, 1991).

Thus, the aim of this research is to conduct regional groundwater studies using high-resolution aeromagnetic data to determine zones of groundwater potential with a view to provide sufficient water for the communities and to understand better the regional groundwater situation in the area.

LOCATION AND GEOLOGY

The study area is situated in the North-Central part of Nigeria and lies between latitudes 8° 00'- 9°30' N and longitudes 6°30'- 8°00' (Figure 1). The most prominent hills in the northeast and north central part have the highest elevation of 770 m; the lowest reliefs of 70 m height are at Muye and Budan along River Niger (Figure 1). The

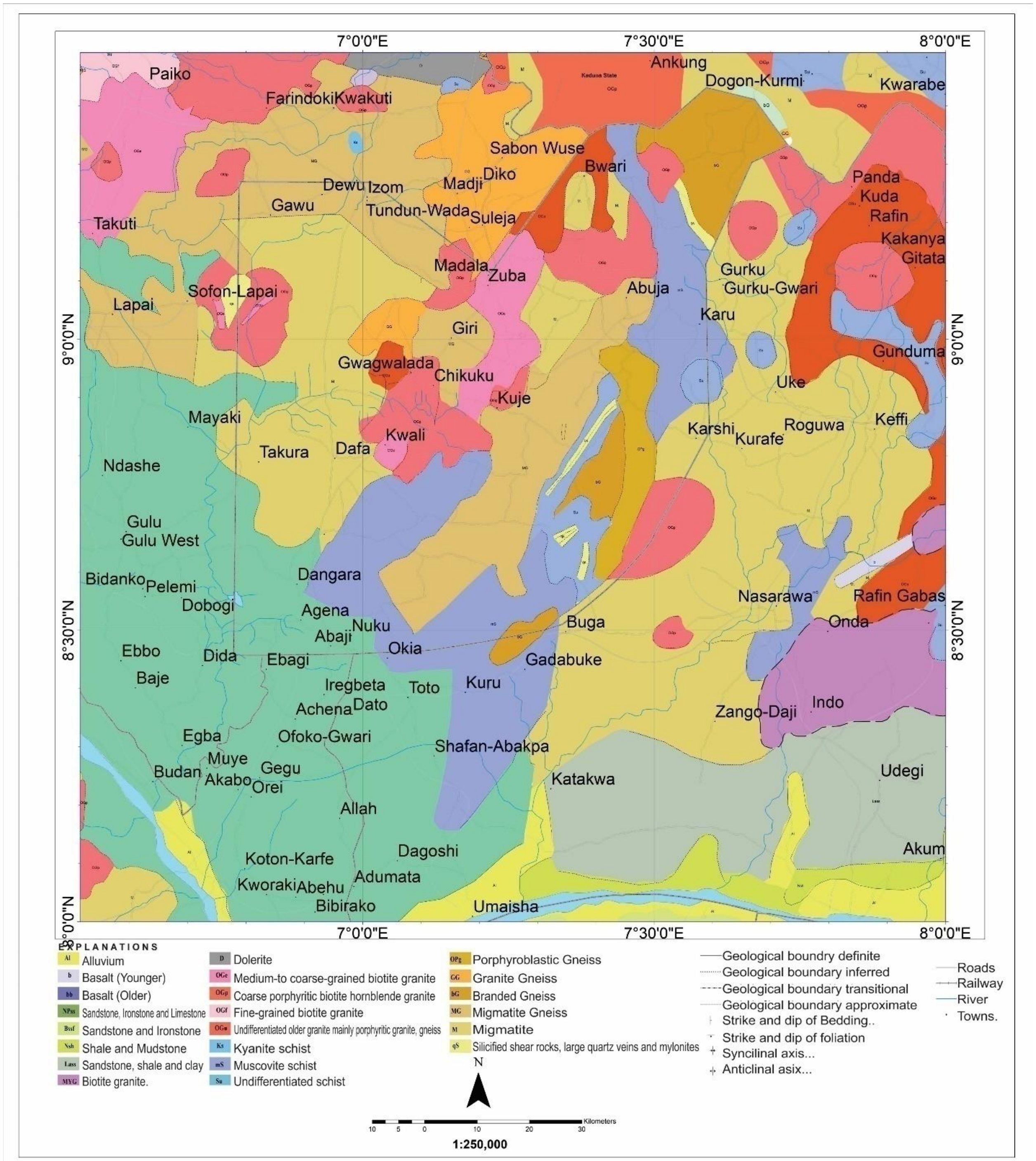


Figure 2. Geological map of the study area (After Nigerian Geological Survey Agency- NGSA, 2011).

geology of the study area comprises, large quartz veins and mylonites, migmatites, migmatitic gneiss, banded gneiss, granite gneiss, porphyroblastic gneiss, undifferentiated schists, muscovite schist, undifferentiated older granite mainly, porphyritic granite, gneiss, fine-grained biotite granite, coarse porphyritic biotite hornblende granite, medium-to coarse grained biotite granite and dolerite. Biotite granite is overlain by Lafia Formation (Figure 2). Some part of the basement complex rocks of the study area has undergone weathering processes to give rise to micaceous sand clay soil and laterite. The Lafia Formation is composed of ferruginized sandstones, loose sands, flaggy mudstones, clays, and claystones. The type locality is in Lafia where many sections occur especially along the bank of the River Amba on the Lafia-Doma road (Obaje, 2009).

The oldest stratigraphic sequence in the Southern Bida Basin in area of study is Lokoja Formation, which unconformably overlies the Precambrian Basement Complex. The basal unit of Lokoja Formation consist of conglomerates, subrounded to well-rounded quartz, feldspars, pebbles and cobbles, especially at the basement-sediment contact. The pebbles are embedded in whitish clayey matrix. The basal conglomerates is overlain by fine to very coarse-grained conglomeratic sandstone. The predominant sandstone facies vary in colour from milky to purple (Adeleye, 1989; Braide, 1992). The alternating sequence of feldspathic sandstone and silt stone, false bedded sandstone, shales and mudstone, black shale, siltstone and sandstone belong to the Patti Formation. The Patti Formation conformably overlies the Lokoja Formation and comprised upto 100 m thick sequences of sandstone, claystone, shale and coaly units exposed between Korton Karfi through Abaji (Ladipo et al., 2011).

The youngest rock sequence in the area is Agbaja Ironstone Formation which overlies the Patti Formation. It forms the protective lateritic capping, consisting of oolithic to pisolitic, concretional and massive ironstone facies. It is about 20 m thick according to Abimbola (1997). The tertiary-recent volcanic rocks in the area consist of the older and younger basalts. The older basalt is found at the southeast of Gunduma, whereas the younger basalt is found at the east of Nasarawa (Figure 2) . The alluvial deposits also found in surroundings of river and stream channels in the area.

In terms of hydrogeology, the study area is dominated by the basement complex rocks of Northern Nigeria where groundwater occurrence is in the weathered zones/un-weathered (fractures/faults) zones. The sandstone beds within Lafia Formation, Lokoja Formation and Patti Formation as well as the river alluvium constitutes good aquifers in the sedimentary part of the study area.

MATERIALS AND METHODS

Nigerian Geological Survey Agency (NGSA) from 2004 to 2009 carried out high-resolution airborne magnetic survey of Nigeria. The aeromagnetic data collected at terrain clearance of 80 m along northwest–southeast flight direction, flight lines spacing of 500 m and a tie line spacing of 2000 m on a scale of 1:100,000. The aeromagnetic data for this study, which covers an area of approximately 27,225 km^2, was obtained from the (NGSA). The international geomagnetic reference field (IGRF) information or data of 2005 were excluded from the aeromagnetic data. Total Magnetic Intensity (TMI) map of the study area shown in Figure 3 was subjected to regional-residual separation using first order Polynomial method of Oasis Montaj software version 8.3. The residual values obtained are presented in Figure 4.

First vertical derivative

Vertical derivatives amplify short-wavelength information at the expense of long-wavelength information. 1VD map, accentuates gradients along edges of shallow magnetic sources (Dobrin and Savit, 1988). It can be used to locate edges of magnetic bodies and to emphasize sources at shallow depths. The formula of 1VD is given by Verduzco et al. (2004) as:

$$1VD = \frac{\partial M}{\partial Z} \quad (1)$$

Where M is the magnetic anomaly and Z is the survey height.

Vertical derivative maps help highlight the details, discontinuities and breaks in anomaly texture (Nabighian, 1972; Miles et al., 2000; Lyatsky et al., 2004; Grauch and Drenth, 2009; Paananen, 2013; Miles and Oneschuk, 2016). 1VD calculation was performed on the residual magnetic grid of the study area using Oasis Montaj software version 8.3. Visual inspection method of lineament extraction was applied on the 1VD map of the study area. ArcGIS software version 10.4.1 was made use of in the performance of geospatial analysis and final preparation of maps. RockWorks software version 16 was used to produce the lineament properties and rose diagram.

RESULTS

High-resolution aeromagnetic data acquired over Abuja and environs were analysed in order to identify suitable groundwater potential zones with a view of providing sufficient water to the community in the area. The TMI map of Abuja and environs are shown in Figure 3, anomalies range from 405.0 to 619.7 nT, while the residual magnetic values of the study area are shown in Figure 4, the magnetic anomalies vary from -104.390 to 87.889 nT. Lineaments extracted from the 1VD map of the area are in Figure 5. The distribution of lineaments by direction was extracted from 1VD map of the study area and is presented in rose diagram in Figure 6, while the lineament density map of Abuja and environs is presented in Figure 7.

Fieldwork carried out in the study area confirmed the presence of fractures. For instance, the fracture shown in Figure 8a was seen on migmatite at Kwaita Sabo Area of FCT-Abuja on latitude 8° 40’ 33.8’’ N and longitude 6° 55’ 28.7’’ E (Figures 5 and 7), while a conjugate fracture (Figure 8b) was seen on undifferentiated older granite at Jankawa in Karu local government area of Nasarawa State on latitude 9° 01’ 06.8’’ N and longitude 7° 45’ 53.9’’ E.

DISCUSSION

The residual magnetic map of the study area reveals

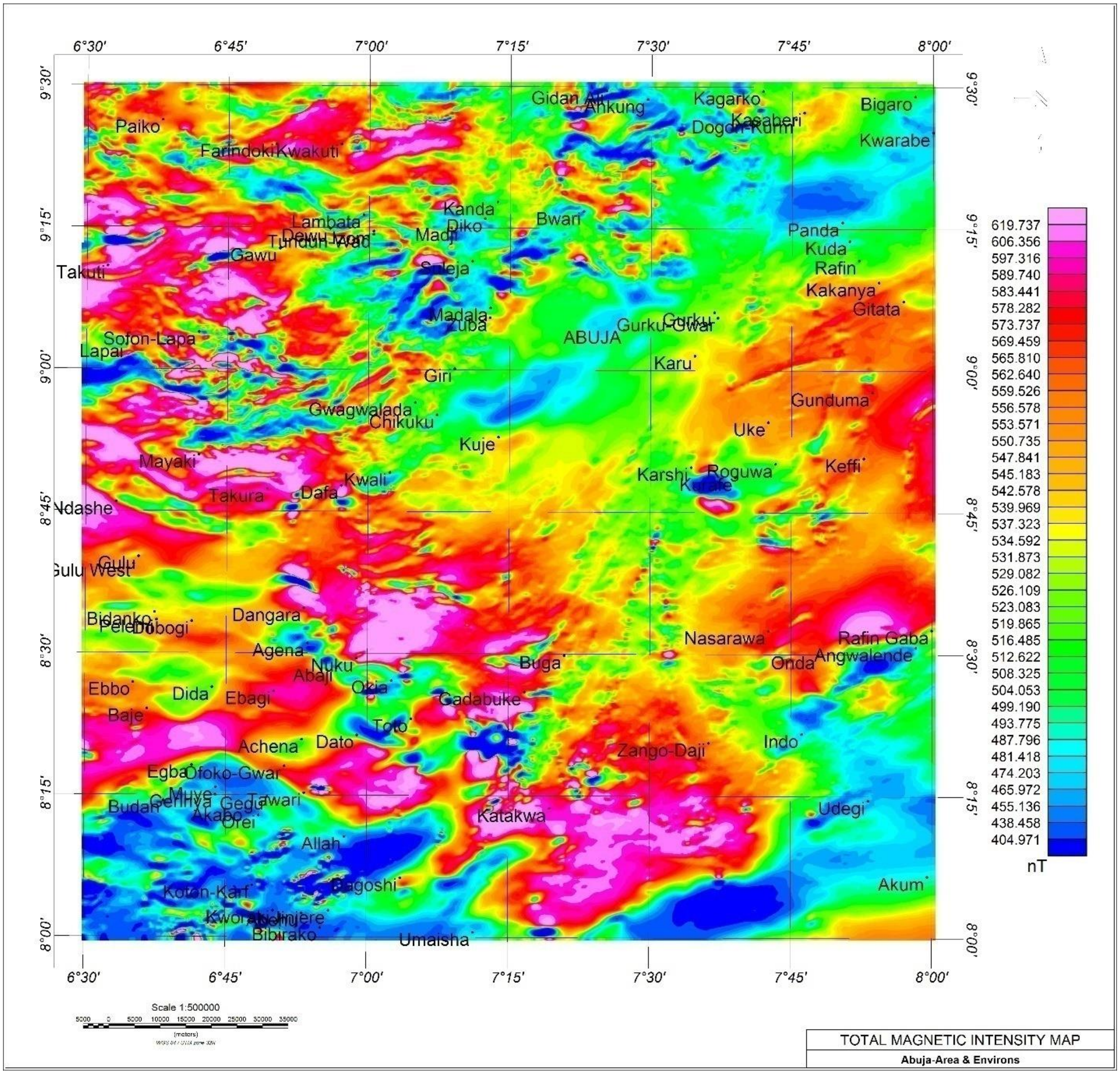


Figure 3. Total magnetic intensity map of the study area (32,500 nT value that was removed from the TMI due to data handling should be added at every point to obtain the actual TMI values in the legend).

anomalies of high and low magnetic values which trends mainly to the NNE-SSW and NE-SW direction (Figure 4). The residual magnetic value of the study area ranges from -104.390 to 87.8889 nT. The lowest residual magnetic values are found around Udegi in the south-eastern part. Other areas with low values are Egba, Muye, Gegu and Allah in the south-western part, while highest magnetic values are observed in areas around Takuti, Mayaki, Nuku and Katawa.

The 1VD map is presented in Figure 5. Lineaments extracted from the 1VD map of the study area are also shown in Figure 5. Lineament analysis is usually done by using frequency or length against azimuth histograms, rose-diagrams, and/or lineament density maps (Zakir et al., 1999). Lineament-length density and lineament frequency are considered in lineament analysis (Greenbaum, 1985; Edet et al., 1998). Lineament density can be analysed by either counting the number of lineaments or calculating the lineament lengths contained within the cell limits (Casas et al., 2000). In this study, lineament analyses were done using rose diagram and lineament density map.

The distribution of lineaments by direction, extracted from 1VD map of the study area is presented in rose

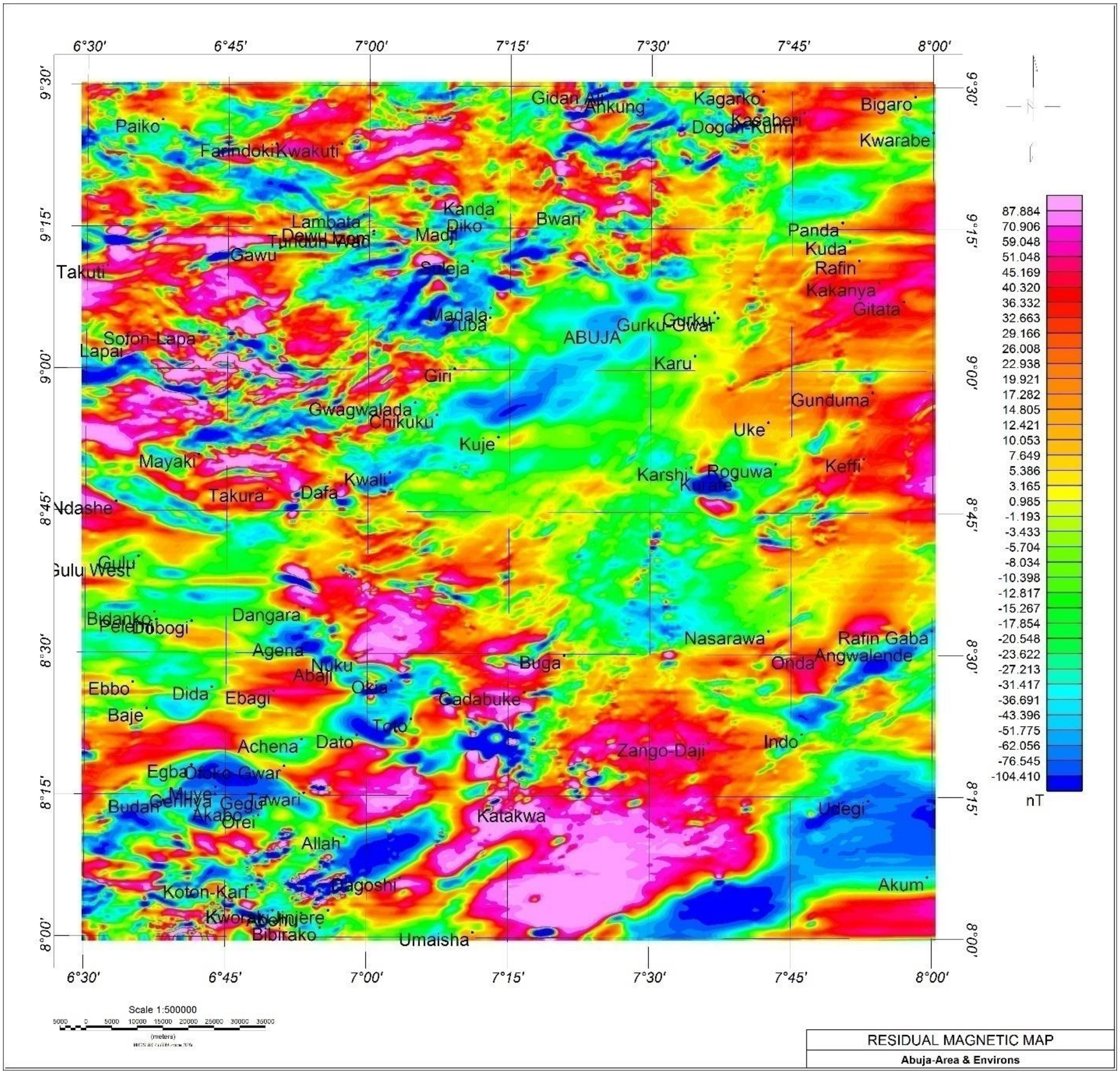


Figure 4. Residual magnetic map of the study area.

diagram (Figure 6). The structural directions of the rose diagram show that the major lineament trends are NNE-SSW 27.47%, NE-SW 25.54%, ENE-WSW 18%, N-S 9.57% and the minor lineament trends are E-W 8.66%, WNW-ESE 5.54%, NNW-SSE 3.09%, and NW-SE 2.16% according to the order of abundance and that NNE-SSW is the dominant lineaments trend direction in the study area (Figures 5 and 6).

The total number of all lineaments derived from 1VD map of the study area is 11352 and range in length from 169.3 m to 65.754 km. The rose diagram from 1VD map of the study area revealed that the major lineaments trend in the study area was NNE-SSW, NE-SW, ENE-WSW Pan-African and N-S pre-Pan-African and the minor lineaments trend was E-W, WNW-ESE, NNW-SSE and NW-SE pre-Pan-African deformation episodes. The Pan-African deformational episode was the most dominant in the study area (Figure 6). These lineaments in the study area were also reported by Fairhead and Green (1989), Fairhead and Okereke (1990), Braide (1992b), Obaje (2009), Bala et al. (2017) and Anudu et al. (2020).

The E-W lineaments were a result of the collision of the West African craton and westward moving plate. The E-W movements is regionally replicated as highly deformed

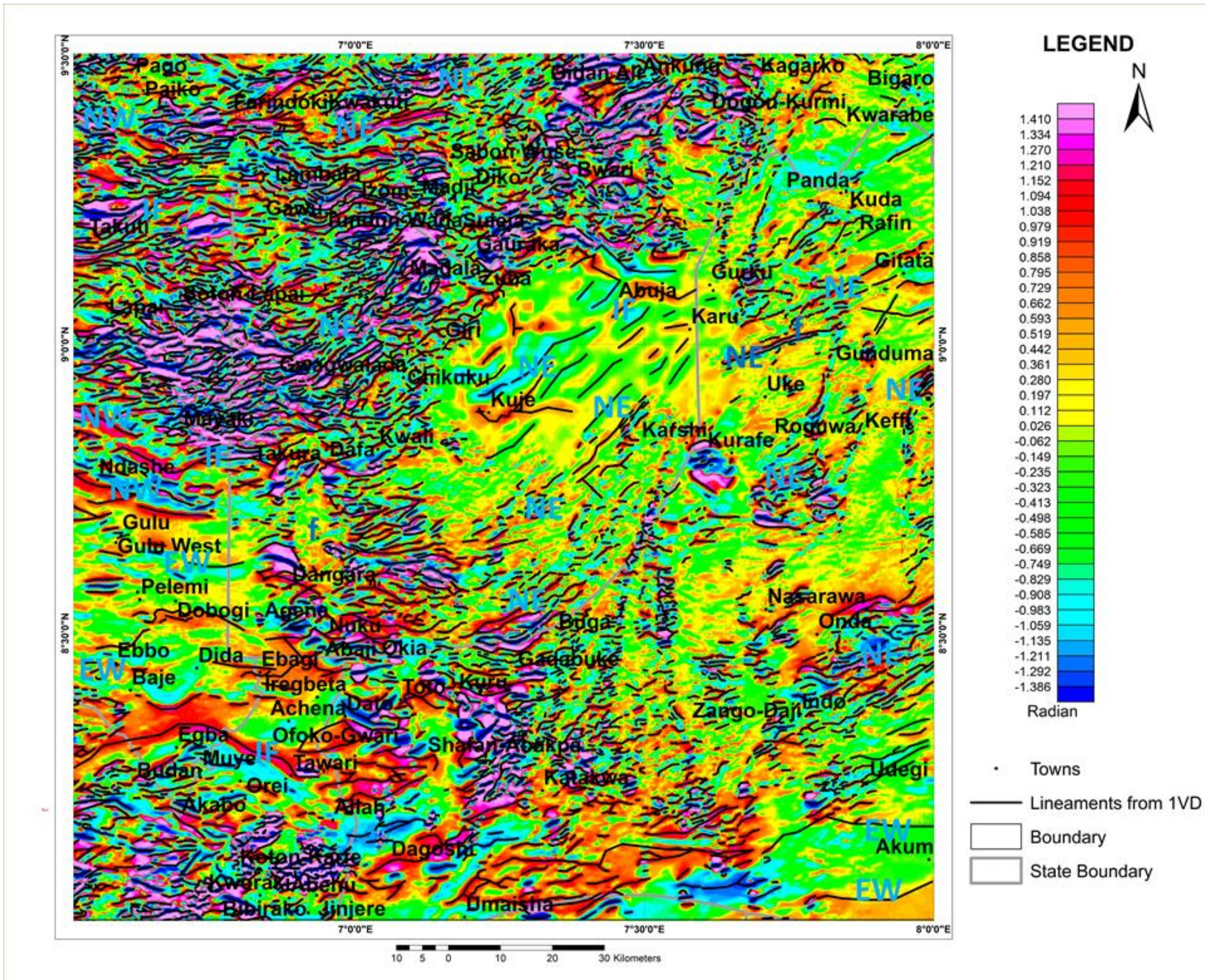
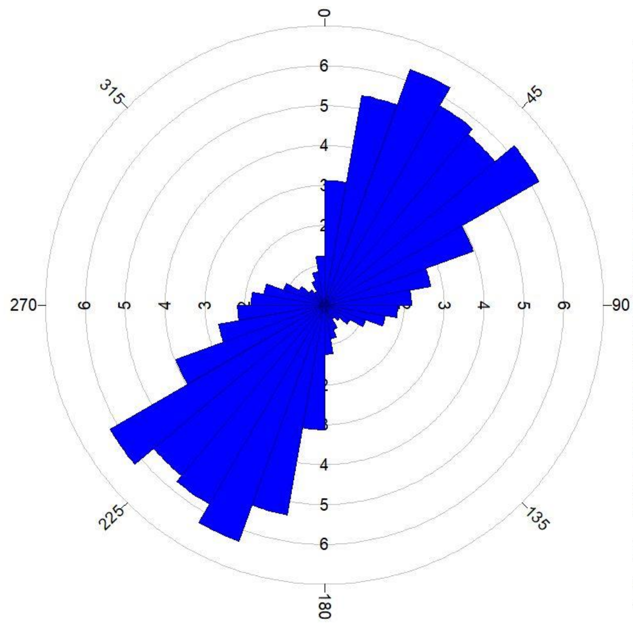


Figure 5. First vertical derivative map of the study area. Zero (0) contour values in the scale bar indicates the contact locations of the causative source bodies. Black lines represent lineaments extracted from IVD map. Shown are the dominant NE-SW lineaments (NE); E-W lineaments (EW); NW-SE lineaments (NW); isoclinal folds (IF); fracture (f) on migmatite at Kwaita Sabo Area of FCT-Abuja; conjugate fracture on undifferentiated older granite at Jankawa in Karu local government area of Nasarawa State.

series of multidirectional orientations common in folds, lineaments and faults in the whole of the Nigeria basement complex and northern Cameroun (McCurry 1971, 1976; Onyeagocha 1984; Toteu et al., 1990). The NE-SW structures are presumably associated with the Pan African orogeny while Pre-Pan African structures are oriented differently to these directions in the basement (Onyeagocha and Ekwueme, 1982; Toteu et al., 1990).

The view of Braide (1992b) was that extensional tectonics played a key role in the evolution of the Bida Basin, especially in its southern part. Extensional basin tectonics were also responsible for the creation of Benue Trough. The E-W lineaments can be seen at the western part of Pelemi at the south-western portion of Abuja and environs underlain by rocks of Bida Basin (Figures 5 and 7), which reveals the fact that extensional tectonics played a key role in the evolution of Southern Bida Basin. Extensional basin tectonics also played a key role in the evolution of the Middle Benue Trough and this can be seen around south-western part of Akum at the south-eastern part of the study area (Fairhead and Green 1989; Fairhead and Okereke 1990).

The result of the application of 1VD technique to the residual magnetic data of the study area indicates that polyphase deformation was pervasive throughout the study area in the form of joints, fractures, faults as well as folds (Figures 5 and 7). Isoclinal fold can be seen at Takuti and Takura at the north-western part; Ofoko-Gwari,Egba,



Statistical Summary	
Calculation Method:	Frequency
Class Interval:	10.0 Degrees
Azimuth Filtering:	Activated
Minimum Azimuth #2:	0.0 Degrees
Maximum Azimuth #2:	360.0 Degrees
Data Type:	Bidirectional
Population:	11,352
Total Length of All Lineations:	22,704.0
Maximum Bin Population:	1,429.0
Mean Bin Population:	630.67
Standard Deviation of Bin Population:	486.74
Maximum Bin Population (%):	6.29
Mean Bin Population (%):	2.78
Standard Deviation of Bin Population (%):	2.14
Maximum Bin Length:	1,429.0
Mean Bin Length:	630.67
Standard Deviation of Bin Lengths:	486.74
Maximum Bin Length (%):	6.29
Mean Bin Length (%):	2.78
Standard Deviation of Bin Lengths (%):	2.14
Vector Mean:	41.2 Degrees
	221.21 Degrees
Confidence Interval:	0.9 Degrees
	(80 Percent)
R-mag:	0.51

Figure 6. Rose diagrams depicting strike trends of mapped lineaments from the first vertical derivative map of the study area. The major lineaments trend corresponds to NNE-SSW, NE-SW, ENE-WSW Pan-African and N-S pre-Pan-African deformational episodes in the study area.

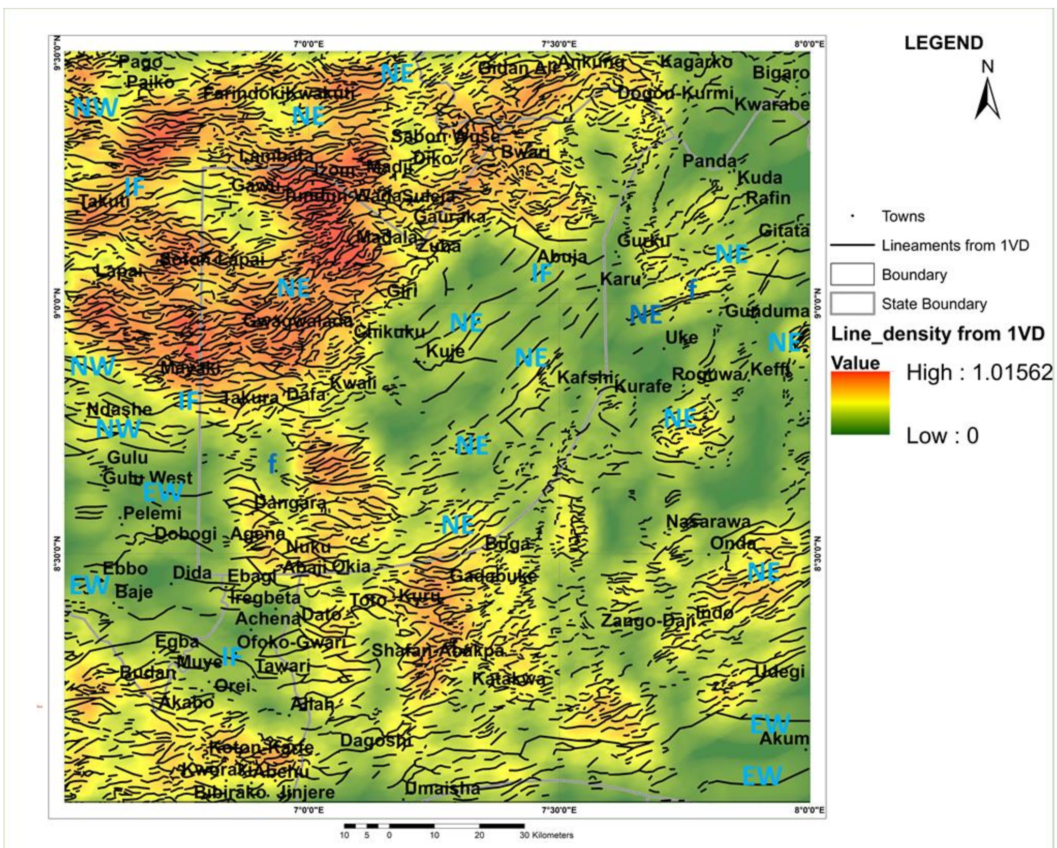


Figure 7. Lineament density map of the study area. Black lines represent lineaments extracted from 1VD map. Colour bar signifies lineament density. High lineament density areas are groundwater exploration targets. Shown are the dominant NE-SW lineaments (NE); E-W lineaments (EW); NW-SE lineaments (NW); isoclinal folds (IF); fracture (f) on migmatite at Kwaita Sabo Area of FCT-Abuja; conjugate fracture on undifferentiated older granite at Jankawa in Karu local government area of Nasarawa State.

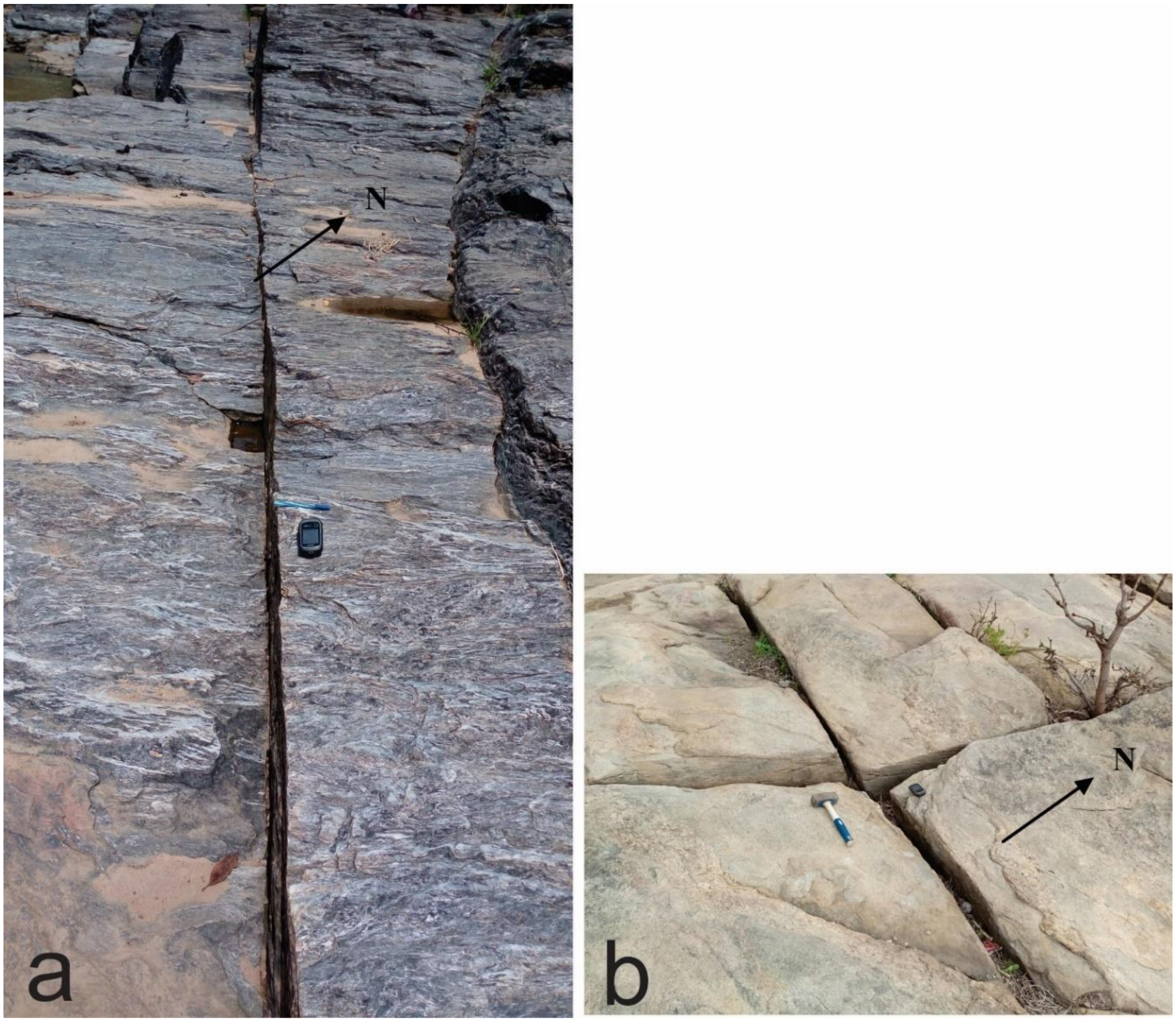


Figure 8. (a) Fracture on migmatite at Kwaita Sabo Area of FCT-Abuja; (b) Conjugate fracture on undifferentiated older granite at Jankawa in Karu local government area of Nasarawa State.

and Tawari at the south-western part and Abuja at the north-central part of the study area (Figures 5 and 7).

According to Edet et al. (1998), the zones of relatively high lineament density are zones of high degree of rock fracturing which are pre-requisite for groundwater conduit development in an area. Areas identified in this research with long length of lineaments and high lineament density serve as conduits for groundwater recharge and are targets for groundwater exploration (Figures 5 and 7). These areas are Dogon-Kurmi, Gitata, Rafin, Gurku, Karshi and Keffi at the north-eastern part; Paiko, Farindoki, Takuti, Lambata, Izom, Tudun Wada, SafonLapai, Mayaki and Gwagwalada at the north-western part; Gidan Ali at the northern part; Takura, Dafa, Dangara, Abaji, Kwali, Zuba, Madalla, Gauraka, Suleja, Kuje, Abuja and Bwari at the central part of the study area. Other areas are Indo, Udegi, Zango-Daji, eastern part of Katakwa, Gadabuke and Buga at the south-eastern part; Budan, Koton-Karfe, Bibirako, Kworaki, Toto, Dagoshi and Umaisha at the south-western part of the study area are targets for groundwater exploration.

Fieldwork carried out in the course of this work identified fractures in the study area. The first fracture (Figure 8a) was seen on migmatite at Kwaita Sabo Area of FCT-Abuja on latitude 8° 40’ 33.8’’ N and longitude 6° 55’ 28.7’’ E (Figures 5 and 7). Conjugate fracture (Figure 8b), an indication of polyphase deformation was seen on undifferentiated older granite at Jankawa in Karu local government area of Nasarawa State on latitude 9° 01’ 06.8’’ N and longitude 7° 45’ 53.9’’ E (Figures 5 and 7). It was discovered that the fractures mapped from the field in this study (Figures 8a, b) were located directly on/and or close to the delimited areas with long length of lineaments and in areas with moderate-high lineament density (Figures 5 and 7). Joints, fractures as well as faults identified in this study could serve as conduits for groundwater recharge in the study area (Figures 5 and 7).

The results obtained from regional groundwater studies using high-resolution aeromagnetic data over Abuja and environs, North Central Nigeria in this work were consistence with the results of previous works carried out within the study area (Adewumi and Salako 2018; Andrew et al., 2018; Ayuba and Nur 2018).

Conclusions

The interpretation of high-resolution aeromagnetic data in Abuja and environs, North- Central Nigeria revealed important structural paterns in the study area. Application of 1VD technique to the residual magnetic data elucidated the deformational activities experienced in the study area as joints, fractures, faults, and folds. Rose diagram from 1VD map provided major lineaments of NE-SW direction. The study indicates that Dogon-Kurmi, Gitata, Rafin, Gurku, Karshi, Keffi, Paiko, Farindoki, Takuti, Lambata, Izom, Tudun Wada, Safon Lapai, Mayaki, Gwagwalada, Gidan Ali, Takura, Dafa, Dangara, Abaji, Kwali, Zuba, Madalla, Gauraka, Suleja, Kuje, Abuja, Bwari, Udegi, Zango-Daji, eastern part of Katakwa, Gadabuke, Buga, Koton-Karfe, Bibirako, Kworaki, Toto, Dagoshi and Umaisha have good groundwater prospect in terms of high lineaments density/long lengths of lineament. Areas identified with long length of lineaments and high lineament densities are therefore suitable for groundwater exploration. The fieldwork carried out also confirmed the presence of long length with moderate-high fractures/lineaments suitable for groundwater exploration. This article recommend that electrical resistivity investigation should be carried out in the afore-mentioned areas with long length of lineaments and high lineament densities, and that well point system should be constructed in these areas to address the water shortages in Abuja and its surroundings.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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