Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v35i2.2026.551
Volume 35(2), June 2026

Geospatial and Aeromagnetic Investigation of Structural Lineaments in the Adamawa/Taraba region, Upper Benue Trough, NE Nigeria: An Implication for Geo-hazard Occurrence

***[1,2]Sebastian Abraham Sunu, [2]Adetola Sunday Oniku and [2]Bello Yusuf Idi**

[1]Department of Petroleum Chemistry & Physics American University of Nigeria (AUN) Yola.
[2]Department of Physics, Modibbo Adama University, Yola, Adamawa State, Nigeria.

*Corresponding Author's Email: abraham.sebastian@aun.edu.ng

ABSTRACT

This study integrates geospatial and aeromagnetic techniques to delineate structural lineaments within the Adamawa-Taraba region of the Upper Benue Trough, northeastern Nigeria, stressing their implications for geo-hazard occurrence. Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) was processed using GIS and High-resolution aeromagnetic data advanced filtering techniques including Reduction-to-Equator (RTE), First Vertical Derivative (FVD), Analytic Signal, Tilt Derivative (TDR), Horizontal Gradient Magnitude (HGM), and Source Parameter Imaging (SPI). The results reveal dominant structural trends oriented NE-SW and NW-SE, consistent with the regional tectonic framework of the Benue Trough. Lineament extraction and lineament density analysis indicate zones of intense fracturing, particularly in the central, southern, and northeastern parts of the study area, reflecting significant tectonic deformation. Depth estimates show variations from shallow depth of approximately 98 m to deep magnetic sources of depth of about 2200 m, corresponding to basement uplifts and sedimentary basins respectively. The spatial correlation between structural lineamentsand lineament density patterns highlights their strong control on geo-hazard distribution, including landslides, flooding, erosion, subsidence, and potential fault reactivation. The study demonstrates that integrated aeromagnetic and geospatial analysis provides an effective approach for delineating subsurface structures and identifying geo-hazard-prone zones, thereby supporting sustainable land-use planning and hazard mitigation strategies in structurally complex terrains.

Keywords:
Structural lineaments,
Geo-hazards,
Aeromagnetic,
Upper Benue Trough.

INTRODUCTION

Structural lineaments depict he structural elements of surface and subsurface geometry of geological discontinuities such as faults, fractures, joints, and lithological boundaries, which crucial in controlling ectonic evolution, groundwater flow, mineralization, and geo-hazard occurrence (Benkhelil, 1989; Ijeh et al., 2019). The deformation history and basin architecture of a rift-related basins, such as the Benue Trough of Nigeria, are influenced by these structures (Wright, 1968). Aeromagnetic and geospatial techniques have proven to be highly effective in delineating such features due to their spatial variability, especially in regions where surface exposures are limited by vegetation cover and sedimentary overburden (Ajakaiye et al., 1986; Abdulsalam et al., 2022).Previous studies have shown that structural trends within the Nigerian Basement Complex and the Benue Trough are predominantly oriented along NE-SW, NW-SE, and N-S directions, reflecting the imprint of Pan-African tectonics and subsequent rifting events (Ajakaiye et al., 1986; Ugwu & Alasi, 2016).

Aeromagnetic investigations across the Benue Trough have successfully delineated basement structures, fault systems, and intrusive bodies, thereby providing insights into subsurface geometry and tectonic evolution (Olatubosun et al., 2022; Abdulsalam et al., 2022). Additionally, integration of aeromagnetic data with remote sensing and GIS-based analysis has enhanced the extraction and interpretation of lineaments, allowing for improved structural mapping and hazard assessment (Ijeh et al., 2019; Bello et al., 2022).Structural lineaments are closely associated with geo-hazards such as landslides, flooding, seismic activity, ground subsidence, and erosion (Bello et al., 2022). In the Adamawa/Taraba region, the presence of active tectonic features, coupled with complex lithological and geomorphological conditions, increases susceptibility to such hazards (Ugwu & Alasi, 2016).

Therefore, understanding the spatial distribution, orientation, and density of lineaments is essential for hazard mitigation, land-use planning, and resource management (Ijeh et al., 2019). Despite several geophysical studies in the Benue Trough, there remains a need for an integrated geospatial and aeromagnetic approach focusing specifically on the Adamawa/Taraba region, particularly in relation to geo-hazard implications. This study aims to bridge this gap by combining Geographic Information System (GIS), remote and high-resolution aeromagnetic datasets to delineate structural lineaments and evaluate their implications for geo-hazard occurrence in northeastern Nigeria.

Regional Setting, Location and Geology of the Study Area

The study area is located in the upper Benue Trough, North-eastern Nigeria (Figure 1), encompassing the geographical expanse formerly designated as Gongola State, now divided into Taraba and Adamawa States in Northeastern Nigeria. Geographically, the area lies approximately between latitudes 6 ° N and 10 ° N and longitudes 9 ° E and 13 ° E covering an area of about 98100 km^2. Climatically, the region falls under the tropical savanna climate (Aw) classification according to the Köppen system, exhibiting marked seasonal variations (Adebayo & Tukur, 1999). The wet season typically extends from April to October, with peak precipitation observed in July and August. Annual precipitation ranges from approximately 700 mm in the northern part to over 1,600 mm in the southern part. The dry season spans from November to March, characterized by Harmattan, a northeasterly trade wind from the Sahara Desert, which contributes to reduced humidity, dusty conditions, and decreased visibility. Temperatures in the region generally range from 25° C to 40° C, with the highest values recorded during the dry season. The hydrology of the region is dominated by two major river systems: the Benue River, forming the southern boundary, serves as a principal tributary of the Niger River, while the Gongola River traversing the central area, is the largest tributary of river Benue, and plays a critical role in irrigation and agricultural activities (Obaje, 2009).

Geologically, the area lies within Benue rift system, a linear intra-continental rift structure that evolved during separation of the African and South American plates (Fairhead & Binks, 1991) in the Cretaceous period, facilitating the opening of the South Atlantic Ocean (Nürnberg & Müller, 1991). The region's geology (Figure 2) is highly complex, encompassing Precambrian basement complex rocks, Cretaceous sedimentary successions, and Tertiary volcanic formations. The Basement Complex, exposed predominantly in eastern Adamawa and Taraba States, comprises ancient metamorphic and igneous rocks such as gneisses, granites, and migmatites, which are over 600 million years old (Petters, 1978; Benkhelil, 1989).

These lithologies form significant physiographic features like the Mandara Mountains and the Mambilla Plateau. The Gongola Basin is part of the larger Benue Trough, predominantly made up of Cretaceous sedimentary rocks, sandstones, shales, and limestones deposited in response to extensional tectonics and rift-related subsidence during the mid to late Mesozoic era (Petters, 1978; Popoff, 1988; Obaje et al., 2006). These sedimentary units contain notable fossil assemblages and hydrocarbon potential, thereby drawing significant interest for petroleum exploration (Dike, 1993; Obaje, 2009). The volcanic provinces of the region, particularly the Mambilla Plateau (elevation >1,600 m), were formed during Tertiary volcanic episodes. These highlands are underlain by basaltic lava flows, contributing to the development of fertile volcanic soils (Obaje, 2009). The Adamawa Plateau, which spans a broader area, consists of both metamorphic basement rocks and volcanic materials. Mineral resources within the study area include limestone, gypsum, granite, and clay, which support a range of local industries. More significantly, the potential reserves of oil and natural gas in the Gongola Basin continue to attract ongoing exploration efforts (Dike, 1993; Obaje, 2009).

The morphological complex terrain comprising steep escarpments of the Mandara and Mambilla Plateaus renders parts of the area susceptible to geohazards such as slope instability and soil erosion. Moreover, seasonal flooding along the Benue and Gongola rivers has considerable implications for agriculture and settlement planning, highlighting the need for sustainable land-use and hazard mitigation strategies.

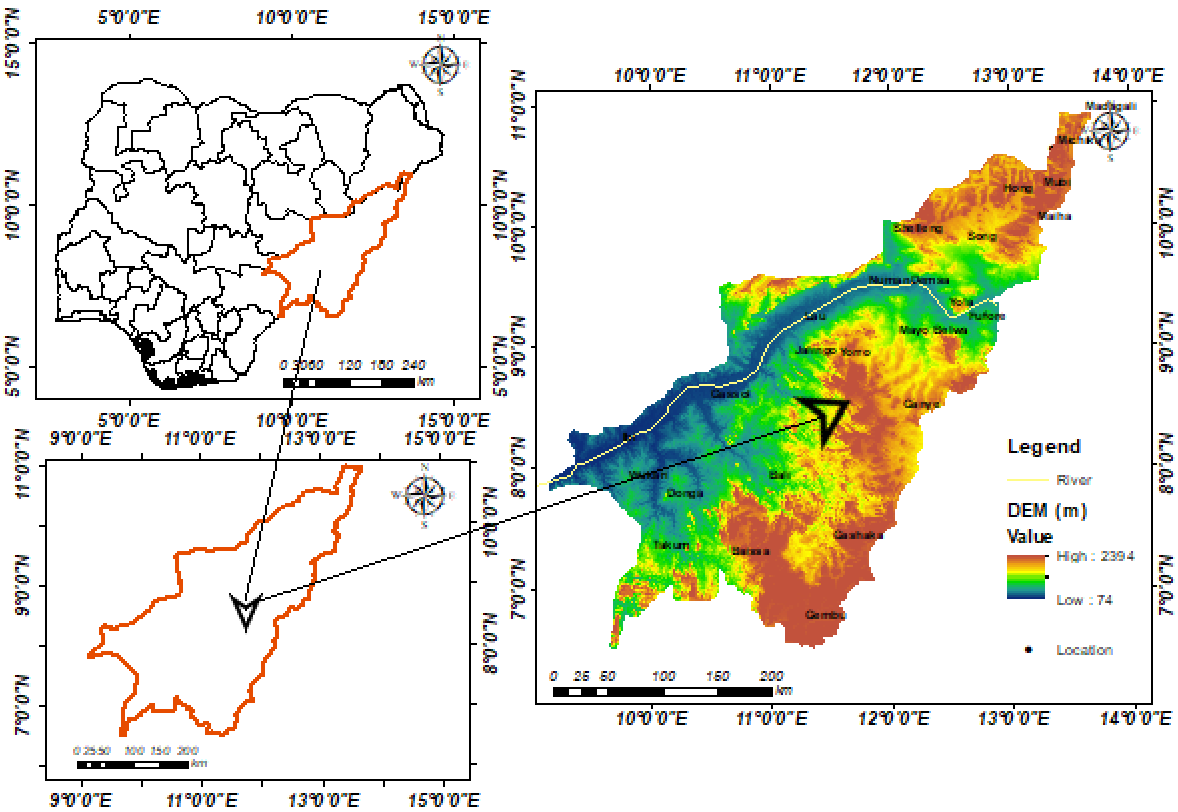

Figure 1: The study area is located in the northern part of the Upper Benue Trough, Nigeria. The Location map was produced using ArcGIS version 10.6. Esri Inc. (2011).

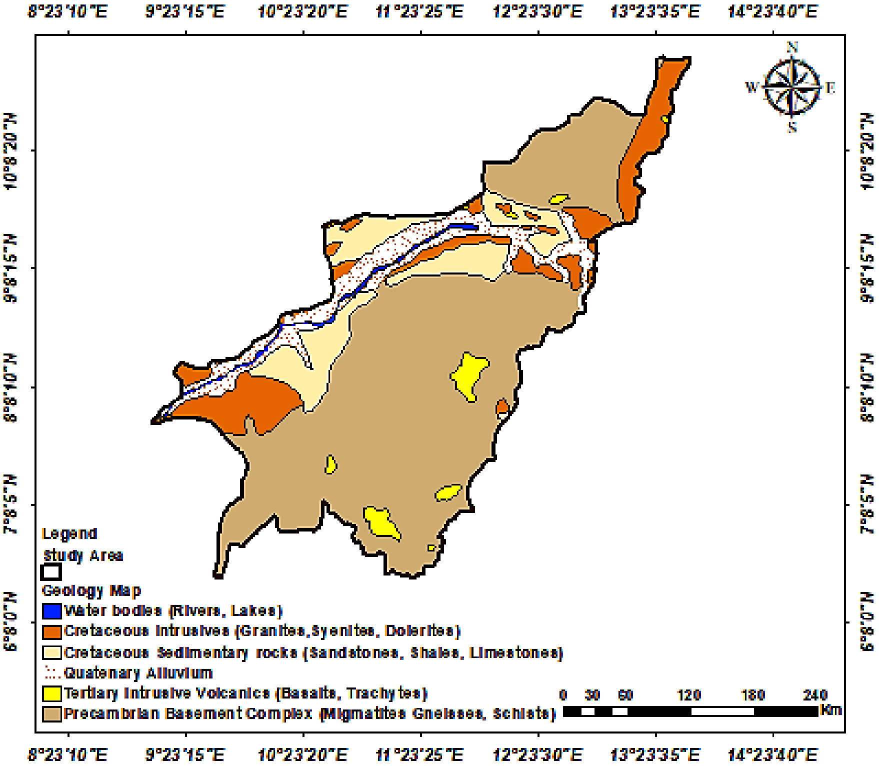

Figure 2: Geology map of the study area

MATERIALS AND METHODS

DEM Data Acquisition and processing

This study employed an integrated dataset comprising Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) obtained from NASA EARTH DATA https://www.earthdata.nasa.gov/data/instruments/srtm (2013). The SRTM data is obtained on a near-global scale at 30 m raster resolution to generate the most complete high-resolution digital topographic database of Earth. Digital Elevation Model (DEM) (Figure 3) processing is a fundamental step in terrain analysis and geo-hazard assessment. In this study, DEM data were processed using ArcGIS 10.6 to derive topographic parameters that influence structural lineaments and geo-hazard occurrence. The DEM (SRTM 30 m) is imported into ArcGIS 10.6 using the Add Data tool. Pre-processing steps include: Projection: Re-project the DEM to a suitable coordinate system (UTM Zone 32N, WGS 84) using the Project Raster tool. Clipping: Extract the study area using Extract by Mask to limit analysis to the Adamawa/Taraba region. For lineament mapping DEM data was illuminated Azimuth 315° at altitude 45° to produce Hillshade which enhances terrain visualization and structural features.

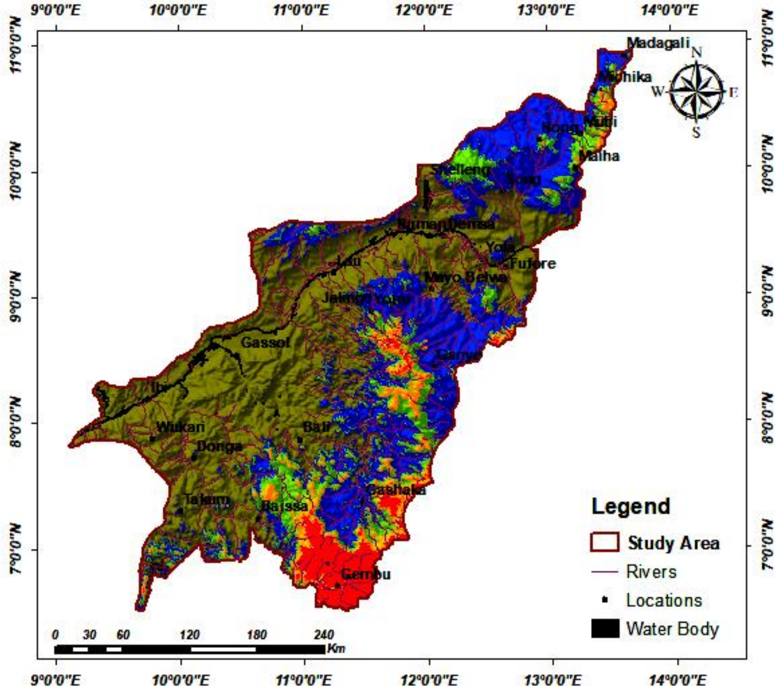

Figure 3: Digital Elevation Model of the study area

Aeromagnetic data acquisition and processing

The Nigerian part of the Benue trough was covered by an aeromagnetic survey conducted by the Nigerian Geological Survey Agency (NGSA) between December 2006 and May 2007. Fugro Airborne Survey conducted Aeromagnetic survey and acquired high-resolution aeromagnetic using 3 x Scintrex CS3 CaesiumVapour Magnetometers sampled at 0.1 second and recorded Total Magnetic Intensity (TMI) data at 0.001nT resolution. The airborne magnetic surveys were flown at 80 m terrain clearance along a series of equally spaced parallel flight lines at 500 m apart trending 135°. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF) formula for 2005. Aeromagnetic datasets provide information on variations in the Earth's magnetic field caused by subsurface geological structures, making them particularly useful for mapping basement faults and lithological contacts (Ajakaiye et al., 1986; Olatubosun et al., 2022). The aeromagnetic data were processed using standard geophysical techniques to enhance structural features. These include Total Magnetic Intensity (TMI) mapping to visualize overall magnetic anomalies, regiona-residual separation using polynomial fitting to isolate shallow structures, and application of derivative filters such as First Vertical Derivative (FVD) and First vertical Derivative (FHD), tilt derivative (TDR) and horizontal gradient magnitude (HGM) to enhance edges and discontinuities (Bello et al., 2022). Additional enhancement techniques, including Analytic Signal and Tilt Derivative, were applied to improve the detection of magnetic source boundaries, as these methods are less sensitive to magnetization direction and effectively delineate subsurface structures (Abdulsalam et al., 2022).

Depth estimation techniques such as Source Parameter Imaging (SPI) and spectral analysis were also employed to determine the depth to magnetic sources and basement configuration (Ugwu & Alasi, 2016).

Total magnetic intensity (TMI)

The total magnetic intensity of the study region indicates magnetic anomalies ranging between 32913 nT to 33206 nT (Figure 4). The study area is characterized by high magnetic anomalies red to pink, moderate magnetic anomalies green to yellow and low magnetic anomalies blue to light blue. The magnetic anomalies are primarily oriented in NE-SW and NW-SE directions, with a minor E-W to NNE-SSW trend. The linear elongated characteristics of the anomalies, especially in the central and northeastern parts of the study area, indicate structurally controlled features such as faults, fractures, and lithological contacts. The NE-SW trend is the most dominant and corresponds to the principal tectonic structure of the Benue Trough, while the NW–SE orientations indicate secondary deformation poly-phase or cross-cutting structural systems in the study area and this is associated with opening of the South Atlantic Ocean in the early cretaceous. These directional patterns suggest a complex tectonic history and highlight zones of structural weakness that may influence subsurface fluid movement and geo-hazard occurrence. The Reduced-to-Equator (RTE) magnetic anomaly map (Figure 5) presents spatial variations in magnetic susceptibility across the study area, with values expressed in nT. The map is subdivided into different magnetic domains labeled as (A1-A3, B-B4, C1-C4).

The distribution and alignment of anomalies suggest strong structural control, likely indicating faults, lineaments, or tectonic boundaries. High-intensity zones such as A1 and B1 may represent shallow magnetic sources or intrusive rocks, whereas low-intensity zones like C1 and C2 may indicate sedimentary basins or deeper, less magnetic materials. Reduction to equator prorocessing enhances anomaly positioning directly over their sources, making the map a valuable tool for interpreting subsurface geology, structural features, geo-hazards and potential mineral or hydrocarbon prospects.

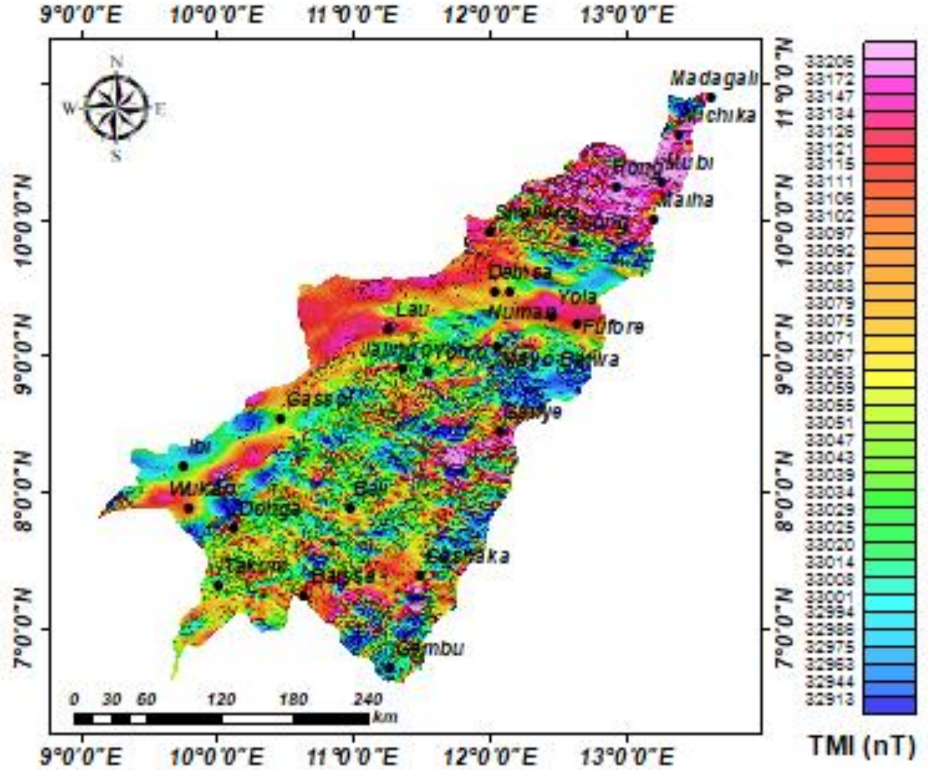

Figure 4: Total magnetic intensity (TMI) of the study Area

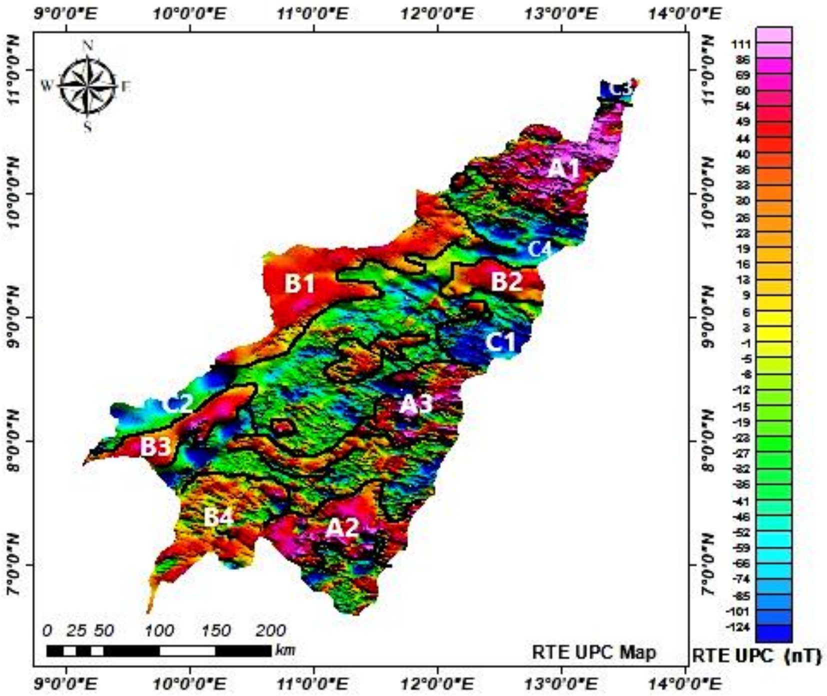

Figure 5: Reduction to equator (RTE) of the study area

Regional and residual aeromagnetic maps (Figures 6 & 7) were prepared using the total magnetic intensity (TMI) data of the study area. The data were corrected using the International Geomagnetic Reference Field (IGRF). The corrected data are then leveled and micro-leveled to remove line-to-line noise and ensure consistency across flight lines. Afterward, the data are interpolated onto a regular grid to produce a continuous magnetic surface.

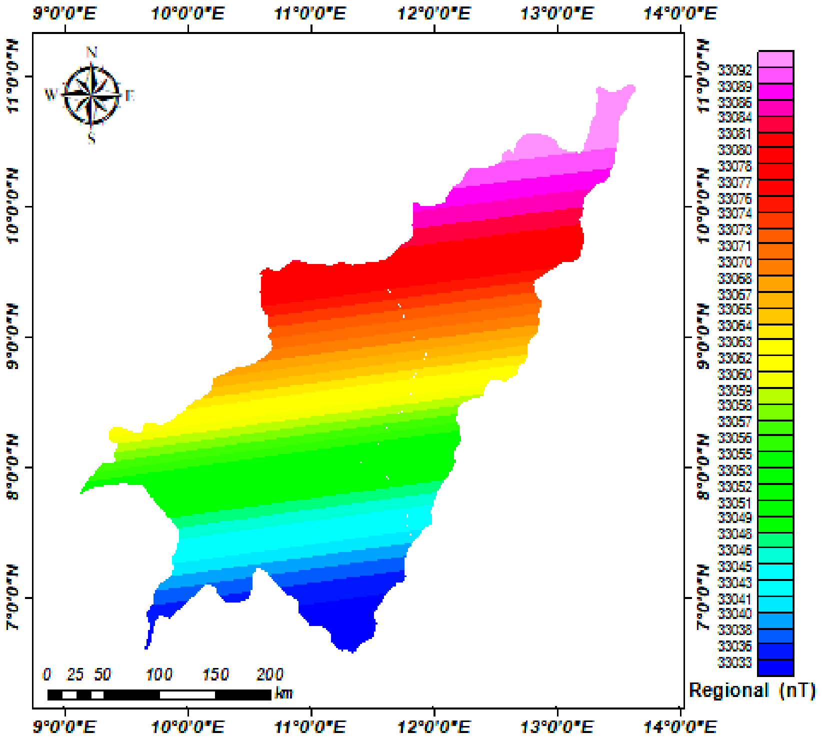

Figure 6: Regional anomaly map of the study area

To generate the regional map, long-wavelength components are extracted using low-pass filtering, which emphasize deep-seated geological sources. The residual map is then obtained by subtracting the regional field from the original (or leveled) magnetic data, effectively isolating short-wavelength anomalies associated with shallow structures. In low-latitude regions, such as the upper Benue Trough an additional Reduction-to-Equator (RTE) correction was applied before or after filtering to properly center anomalies over their sources. These steps collectively allow for clear separation and interpretation of deep versus shallow magnetic features in aeromagnetic studies

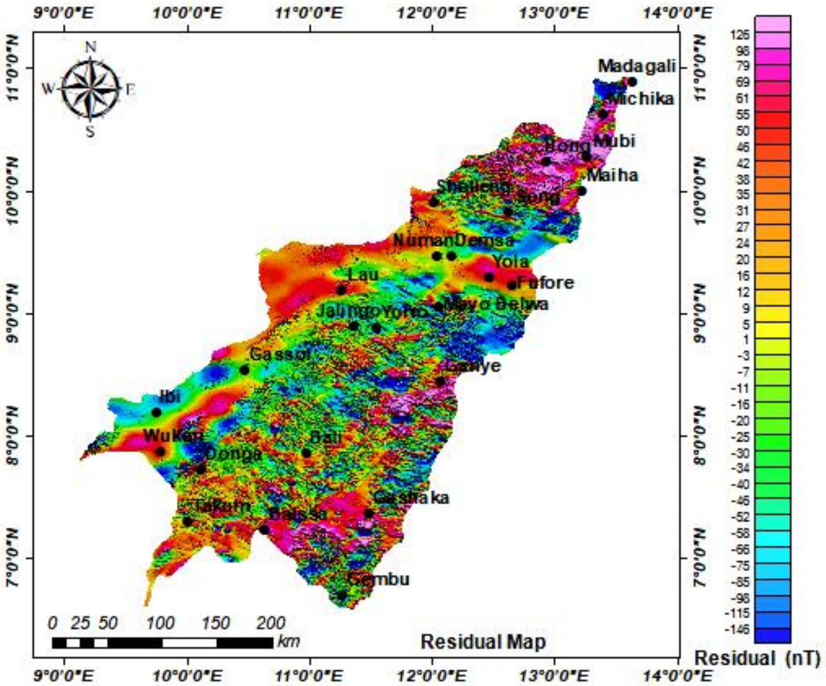

Figure 7: Residual anomaly map of the study area

First vertical derivative (FVD)

First vertical derivative (vertical gradient) enhancement filter usually derived from total magnetic intensity calculates the rate of change of magnetic (signal) field (Milligan & Gunn 1997) this is to resolve magnetic sources (anomalies) on top of individual structures in the total magnetic intensity data and, and suppressing the regional field of the data (Waheed et al., 2023). It also makes anomalies smaller in width and matches the causative body more closely. Vertical derivative transforms facilitate the interpretation of reduced-to-equator magnetic data. They are enhancement techniques that amplify the shorter wavelength anomalies relative to those with longer wavelengths (Phillips, 2000). The nth-order vertical derivatives for a given potential field *(x, y, z)* are calculated as follows: The transformation was implemented in Oasis Montaj software using Fourier domain techniques:

$$FVD(x,y) = \frac{\partial\eta T(x,y,z)}{\partial z\eta} = F^{-1}\left[\kappa|\eta|F\big(T(x,y,z)\big)\right] \qquad (1)$$

$$\kappa = \sqrt{\kappa_x^2 + \kappa_y^2} \qquad (2)$$

$T(x,y)$= reduced-to-equator magnetic field and $z$represents the vertical direction, F = operator of the Fourier Transform, F^{-1}= inverse of theFourier Transform and$\kappa_x$andκ_y= wave numbers in the directions of x and y. By implication, the product of the transformed potential and $\kappa$to any exponent will magnify the short wavelength anomaly of the magnetic field (potential field) associated with near surface anomaly (sources) while attenuating long wavelength components.

Analytic Signal (3D)

Analytic signal Structural filters are crucial tools for deciphering the edges of magnetic sources, and hence the lateral extent of magnetic sources and in Adamawa/Taraba region, these could be potential locations for geo-hazards and mineral exploration targets (Salawu, et., al 2019). The maxima produced by the analytic signal amplitude (Nabighian, 1972), over linear structural bodies such as dykes, faults, and fractures are typically located directly above or very close to the edges of the causative magnetic (anomalies) sources, without considering the direction of magnetization (Nabighian, 1972; Roest et al., 1992; MacLeod et al., 1993). This property makes the analytic signal particularly effective for delineating subsurface structural boundaries and mapping lineaments in low magnetic latitude regions, where conventional magnetic interpretation techniques such as reduction-to-pole are often unreliable (Blakely, 1995; Li, 2006). Consequently, the amplitude peaks can be used to accurately trace the geometry, continuity, and orientation of geological structures (Salem et al., 2007; Reid et al., 2014), providing valuable constraints on the tectonic framework and identifying zones of structural weakness that may control geo-hazard occurrence (Cooper & Cowan, 2006). The absolute value (amplitude) of analytic signal(AS) may be derived from the square root of the sum of the vertical and horizontal derivatives of the total magnetic field (Roset et al.,1992) expressed in equation 3:

$$AS(x,y) = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \qquad (3)$$

$Where, \frac{\partial M}{\partial y}, \frac{\partial M}{\partial z}$= are first derivatives of the total magnetic sources.

In an attempt to map structural bodies in Adamawa/Taraba region, analytic signal algorithm was applied.

Tilt derivative (TDR)

The tilt derivative (Miller & Singh 1994; Oruç & Keskinsezer, 2008) is an enhancement filter used in mapping shallow basement features (structures) structures (Shahverdi et al. 2017; Ibraheem et al. 2018) and edges or contacts of causative sources (anomalies). The tilt derivative amplitude is varies between -π/2 and π/2; positive values are located over the sources, zero values at/near the source edge and negative values are located away from the source (Verduzco et al., 2004). Thefilter is given by the arctangent of the ratio of the vertical derivative of the potential field to its total horizontal derivative expressed in equation 4:

$$TDR = tan^{-1}\left(\frac{VDR}{THDR}\right) \qquad (4)$$

Horizontal gradient magnitude (HGM)

Horizontal Gradient Magnitude (HGM) filtering is an effective edge-detection technique used in aeromagnetic data interpretation to delineate subsurface geological structures such as faults, contacts, and dykes by enhancing zones of high magnetic susceptibility contrast (Blakely, 1995; Cordell & Grauch, 1985). It computes the horizontal rate of change of the magnetic field, producing maxima directly over the edges of causative bodies and enabling accurate mapping of structural lineaments (Roest et al., 1992). The method is particularly advantageous in low magnetic latitude regions due to its independence from magnetization direction, unlike reduction-to-pole techniques (Reid et al., 1990; Salem et al., 2007). Although HGM provides clear structural delineation and is less sensitive to noise than higher-order derivatives, it is often integrated with other filters such as FVD, ASA, and TDR to improve interpretation, as it has limited capability in precise depth estimation and may be affected by overlapping anomalies.

$$HGM = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2} \qquad (5)$$

$Where, \frac{\partial M}{\partial x}, \frac{\partial M}{\partial y}$= are the gradients in the *x* (east-west) and *y* (north-south) directions, respectively. The resulting HGM map enhances linear features and produces sharp peaks directly over the edges of magnetized bodies, making it especially effective for mapping structural lineaments (Roest et al., 1992).

Source parameter imaging (SPI)

Source parameter imaging (SPI) is a filter applied to magnetic data in order to estimate depth to the top of magnetic sources (anomaly) (Thurston & Smith, 1997). Source Parameter imaging make use of the local wave number to obtain depths to magnetic sources expressed as in equation 6:

$$\kappa(x,y) = \frac{\frac{\partial^2}{\partial x \partial z}\frac{\partial M}{\partial x} + \frac{\partial^2}{\partial x \partial z}\frac{\partial M}{\partial y} + \frac{\partial^2}{\partial z^2}\frac{\partial M}{\partial z}}{|A(x,y)^2|} \qquad (6)$$

$\frac{\partial^2}{\partial x \partial z}\frac{\partial M}{\partial x}$= Mixed derivative: change of vertical derivative along *x*, or equivalently change of horizontal derivative with depth.

$\frac{\partial^2}{\partial x \partial z}\frac{\partial M}{\partial y}$= Mixed derivative involving *y* and *z*

$\frac{\partial^2}{\partial z^2}\frac{\partial M}{\partial z}$= Second vertical derivative of magnetic anomaly.

$|A(x, y)|$=Analytic Signal (As) Filter. $\kappa(x,y)$= Local wavenumber at horizontal position (x,y) used to estimate depth source

The reciprocal of the local wavenumber give the depths to magnetic sources (Salem,et al 2014; Ma & Li, 2013). expressed in equation 7:

$$D_{x=0} = \frac{1}{\kappa(x,y)_{max}} \qquad (7)$$

RESULTS AND DISCUSSION

DEM Shaded Relief (Hillshade)

The shaded relief map of the study Region within the Benue Trough reveals pronounced variations in topography that reflect underlying geological structures and tectonic processes (Figure 8). The image highlights a heterogeneous terrain characterized by alternating high and low relief zones, with the darker tones indicating elevated or structurally resistant areas and lighter tones corresponding to relatively low regions, likely associated with sedimentary deposits. Lineaments were manually and automatic extraction were applird for tectonic structural features representation of the study area. The superimposed lineaments (red) clearly delineate linear features interpreted as faults, fractures, and lithological boundaries. A high concentration of lineaments is observed in the central and southern parts of the map, coinciding with zones of rugged and elevated terrain. This suggests strong structural control on the landscape, where tectonic deformation has influenced erosion patterns and surface morphology (Benkhelil, 1989; Wright, 1981).

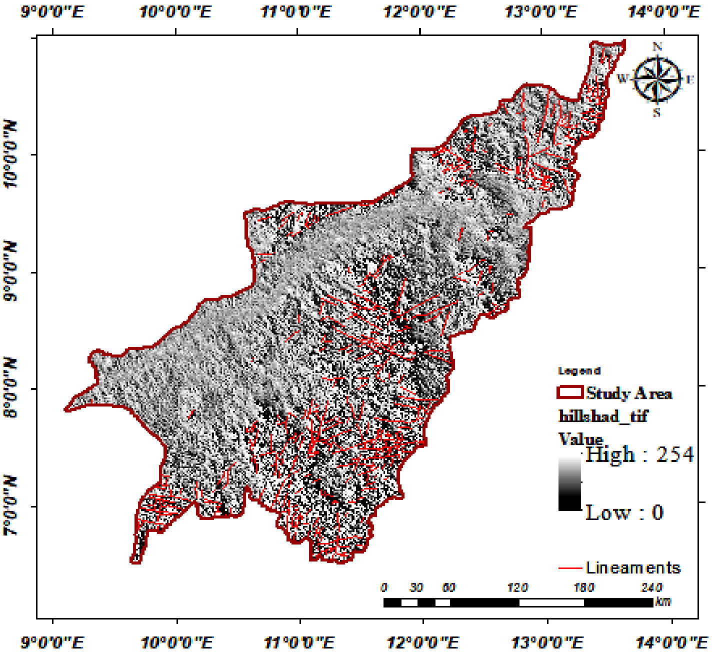

Figure 8: Hillshade map derived from DEM of the study area

The First Vertical Derivative (FVD) map (Figure 9) indicates sharp lateral variations in the magnetic field, thereby enhancing near-surface structural features and discriminating lithological boundaries and contacts within the study area. High magnetic gradient (HG) zones are dominant in the central part of the study known as the Eastern Nigeria Basement Complex and the northeastern basement terrain indicates regions of shallow magnetic sources associated with crystalline basement rocks, structural highs, and possible intrusive bodies (basement complex). In contrast, the low magnetic gradient (LG) zones correspond to relatively deeper magnetic sources typical of sedimentary cover sequences within the Benue Trough. The prominent NE-SW trending linear features observed across the map represent major tectonic lineaments and faults systems that likely controlled sedimentation, magmatic intrusions, and fluid migration pathways. The clearly defined boundary between HG and LG zones marks the inferred basement-sedimentary contact, suggesting significant structural control and possible faulted contacts. These structural discontinuities are critical in geo-hazard assessment, as they may act as zones of weakened rock integrity, groundwater accumulation, and increased susceptibility to seismic activity, subsidence, or slope instability.

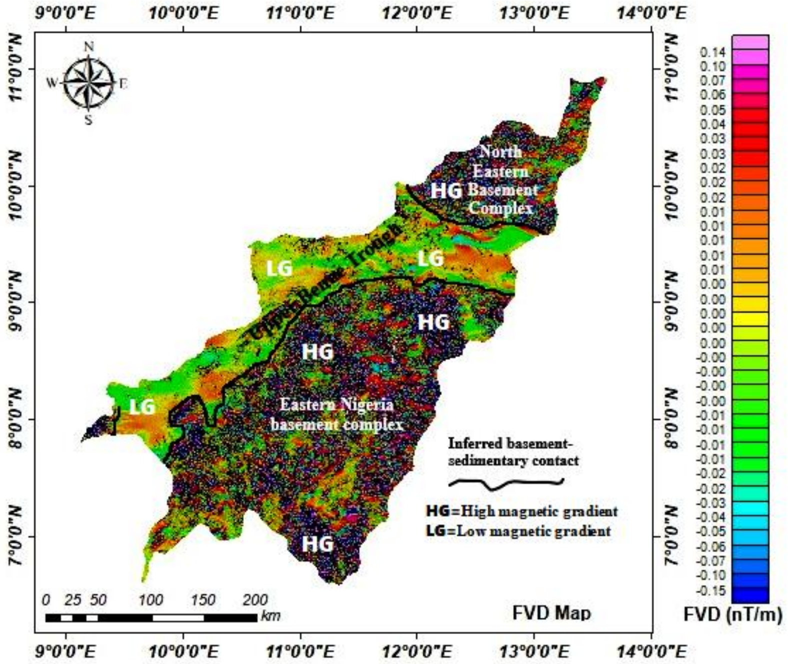

Figure 9: First vertical derivative (FVD) map of the study area

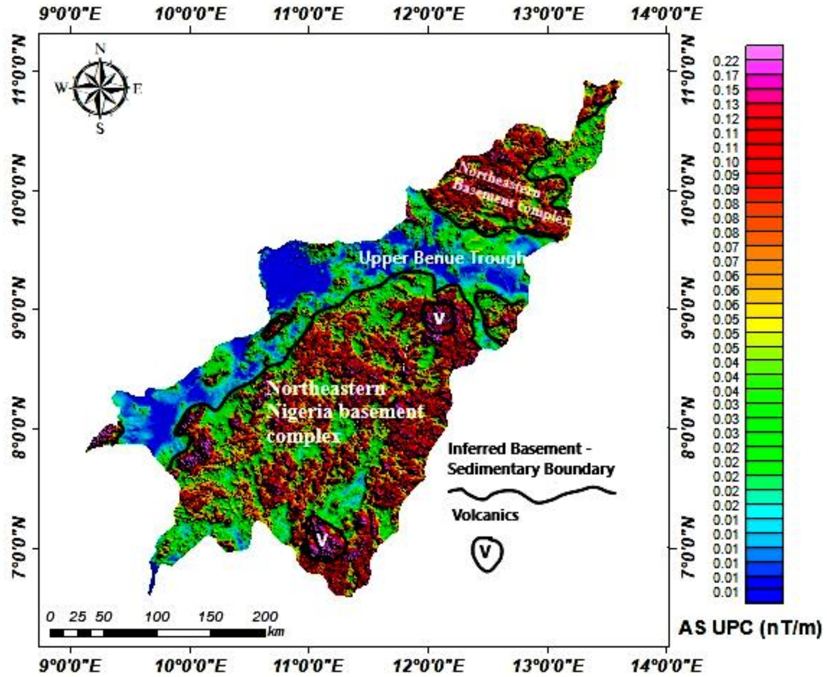

Figure 10: Analytic signal (AS) of the study area

Tilt derivative

The Tilt Derivative (TDR) map (Figure 11) of the study area reveals a structurally complex terrain dominated by NE-SW trending lineaments that represent major fault zones and fracture systems associated with the Benue Trough tectonics. From a geo-hazard assessment perspective, these linear zones-particularly the near-zero tilt channels marking structural boundaries-indicate areas of crustal weakness that may be susceptible to seismic reactivation, ground instability, and differential settlement. It ranges –1.30 to +1.36 radians-typical. The high positive tilt anomalies (red-pink) suggest shallow igneous intrusions and basement highs, with intersecting lineaments which may be a zone of slope failure due to fractured rocks. The broad negative tilt zones (green-blue) likely correspond to deeper sedimentary basins with thicker, less consolidated materials that may be vulnerable to subsidence, erosion, flooding, under intense rainfall or seismic loading. The intersection of major lineaments represents structurally weakened nodes that could localize seismic energy release, enhance groundwater flow pathways, and increase susceptibility to landslides or gully erosion. Overall, the TDR map highlights fault-controlled zones and sediment-filled depressions as priority areas for detailed geotechnical, seismic, and hydrogeological investigations in regional geo-hazard planning.

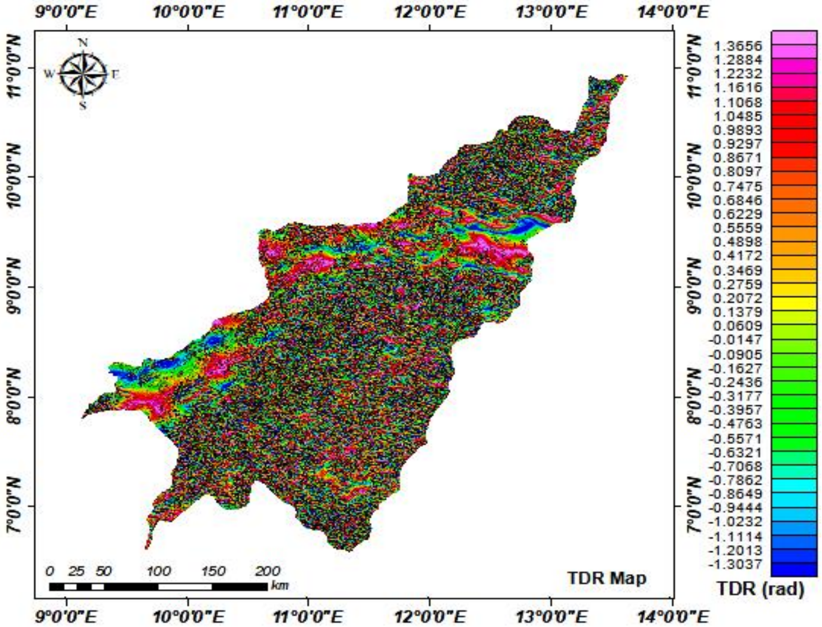

Figure 11: Tilt derivative (TDR) map of the study area

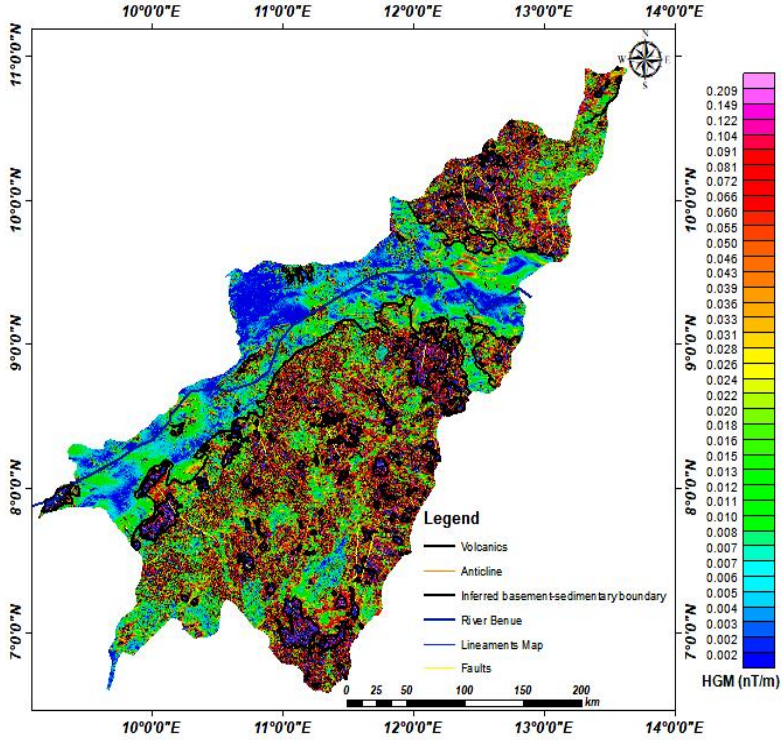

Figure 12: Horizontal gradient magnitude (HGM) Map of the study area

The Source Parameter Imaging (SPI)

The Source Parameter Imaging (SPI) map (Figure 13) reveals significant spatial variation and distribution in depth to magnetic (anomalies) sources across the study area, ranging from shallow depth (~98 m) to very deep (~2283 m). A dominant NE-SW trending deep zone in the central region indicates a structurally controlled trough or sedimentary depocenter associated with faulting and basement subsidence (Nwogbo, 1987; Nuraddeen & Ibrahim, 2020; Chinwuko et al., 2012) and is also associated with tectonic rifting of the in the early cretaceous during the pan African orogeny. Intermediate depths (300 -700 m) mark transitional zones between basement highs and depressions, often corresponding to steep basement gradients, fracture concentrations, and lithological boundaries. In contrast, shallow zones represent basement uplifts or near-surface igneous intrusions with higher magnetic susceptibility and reduced sediment cover. Overall, the SPI pattern reflects a tectonically complex terrain characterized by pronounced basement relief, where deeper basinal areas favor sediment accumulation and groundwater storage, while shallow and structurally weakened zones influence the occurrence of geo-hazards such as flooding, erosion, landslides, and structural instability.

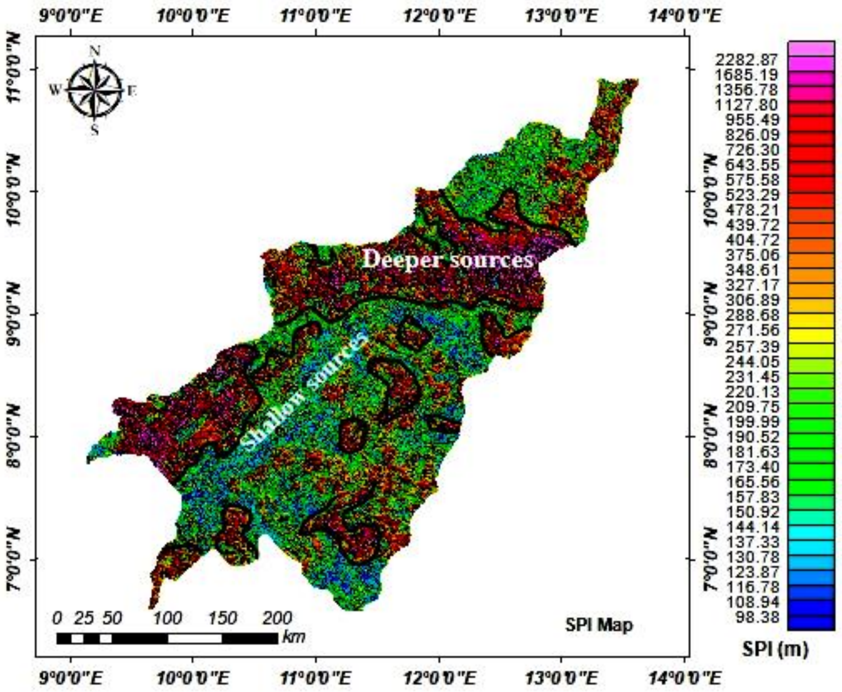

Figure 13: Source Parameter Imaging (SPI) map of the study area

Structural lineament Interpretation

Lineaments were extracted manually and semi-automatic digitization using gradient magnitude thresholds. The identified features were analyzed in relation to geological boundaries, known faults, and topographic expressions. Rose diagram analysis was applied to determine dominant structural trends. Overlay analysis with lineament density maps was carried out to assess potential geo-hazard relationships.The lineament map (Figure 14a) illustrates the spatial distribution and concentrations of structural lineaments and mapped faults from digital elevation model (DEM) across the study area, with the corresponding a rose diagram showing their widespread distribution and orientation (Figure 14b). The lineaments are variably distributed, with perceptible clustering in the central and northeastern portions, suggesting zones of increased structural deformation. Rose diagram reveals dominant structural trends primarily in the NE-SW and NW-SE directions Figure 14b), with minor N-S orientations. The lineament density across the study area (Figure 15a) were categorized into very low, low, moderate, high, and very high classes, alongside with fault rose diagram showing the dominant structural orientations in NE-SW and NW-SE, with minor N-S directions (Figure 15b). The structural lineament derived from the first vertical derivative filter (FVD) (Figure 16a) and horizontal gradient magnitude (HGM) (Figure 18a) confirmed or exhibited similar orientations in NE-SW and NW-SE, with minor N-S directions (Figure 16b, 17b and 18b). Both the lineament derived from DEM, FVD and HGM with lineament density map superimposed on the structural trends for the Adamawa-Taraba region within the Upper Benue Trough reveals a heterogeneous distribution of structural features, reflecting varying degrees of tectonic deformation across the area. The orientation and spatial distribution of the faults in NE-SW and NW -SE (Figure 15b, 17b and 19b) indicating that the structural rends is consistent with the regional tectonic stress regime of the Benue Trough (Olade, 1975; Benkhelil, 1989). The lineament density distribution (Figure 15a, 17a and 19a) shows high to very high lineament density zones are concentrated in the central, southern, and northeastern parts of the region, indicating areas of intense fracturing and structural deformation. In contrast, areas with low lineament density reflect relatively stable and less fractured rock formations. The rose diagram reveals that the dominant lineament trends are oriented. The intersection and alignment of these lineaments highlight structurally controlled zones that significantly influence geo-hazard occurrence and landscape evolution within the study area.

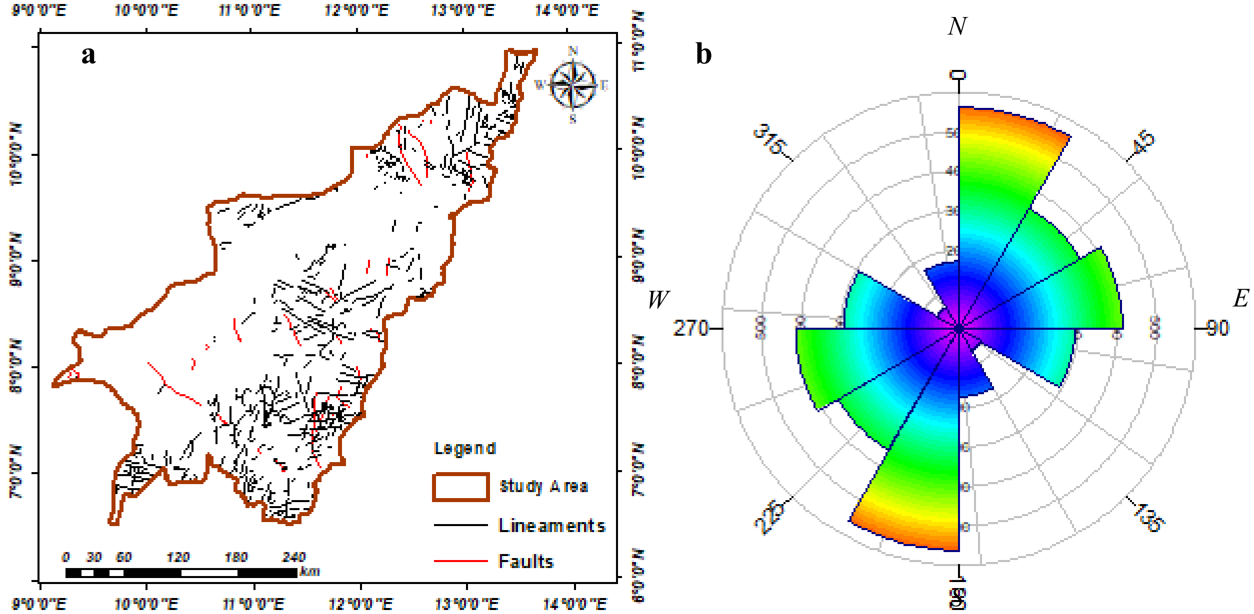

Figure 14: (a)Structural Tectonic Lineament derived from DEM and (b) Rose Diagram of Lineament Orientation in the Adamawa-Taraba Region, Upper Benue Trough, derived from DEM

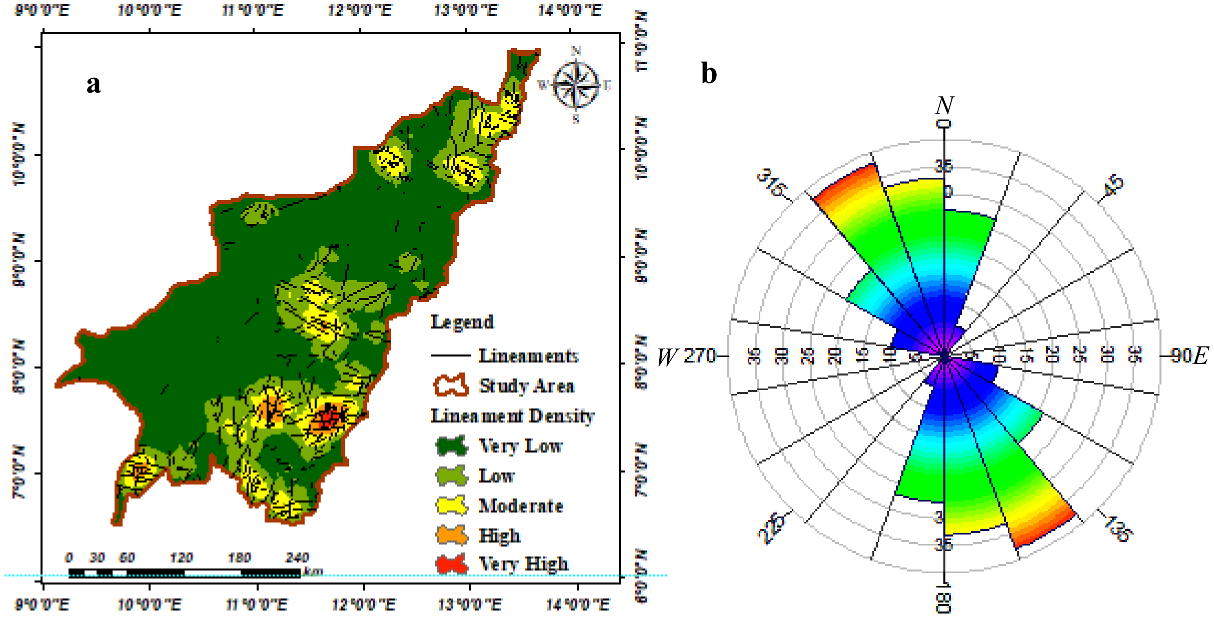

Figure 15: (a) Lineament density map and (b) Rose diagram of fault orientation in the Adamawa-Taraba region, Upper Benue Trough

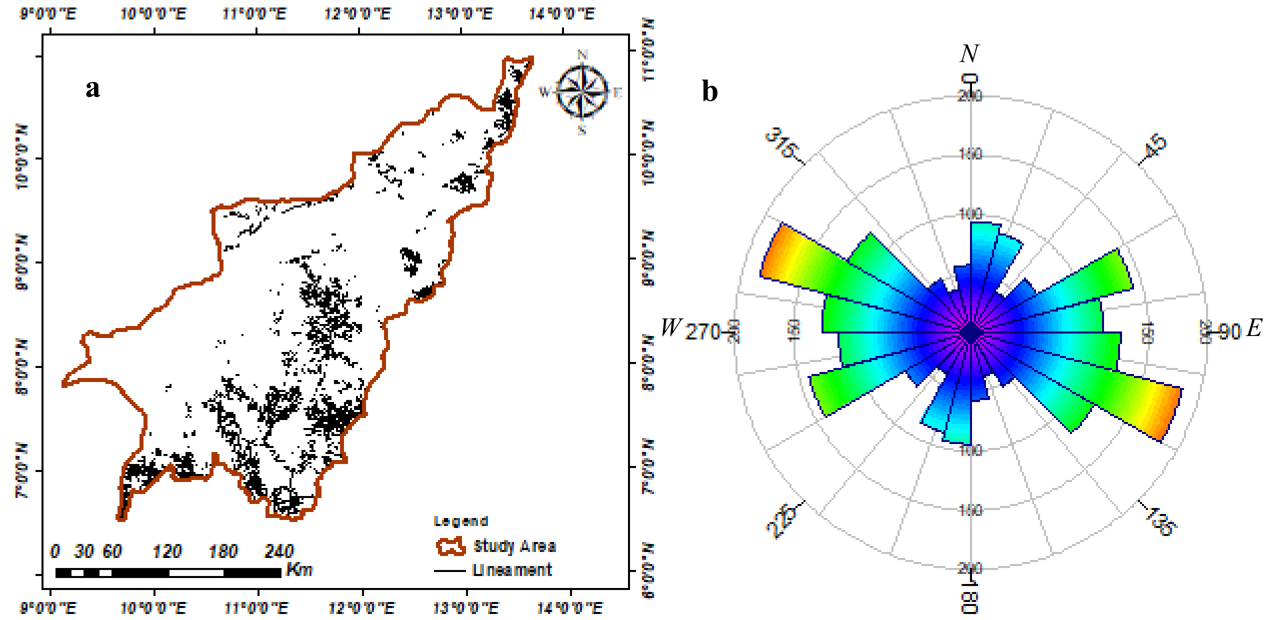

Figure 16: Lineaments derived from the FVD in the study area Upper Benue Trough Northeastern Nigeria (b) Rose diagram of fault orientation in the Adamawa-Taraba region, Upper Benue Trough

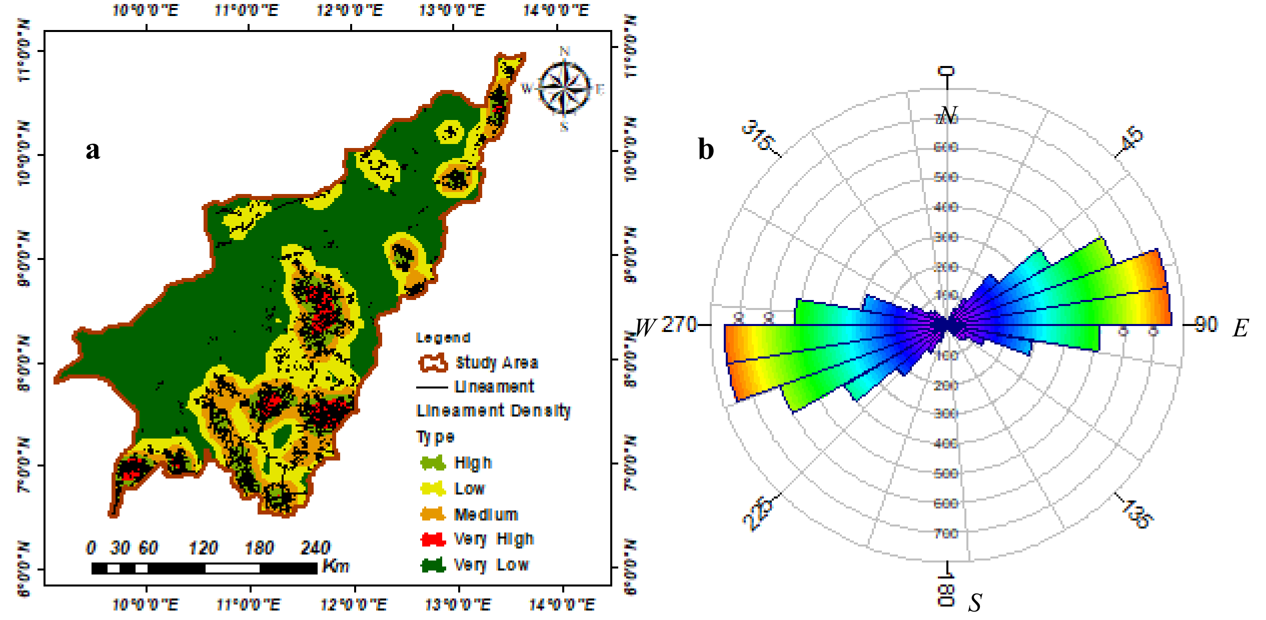

Figure 17: (a) Lineamentsdensity derived from the FVD in the study area Upper Benue TroughNortheastern Nigeria (b) Rose diagram reveals the dominant structural trends within the study area, with prominent orientations observed along the N-S and E-W directions, as well as subordinate trends along the NE-SW and NW- SE axes.

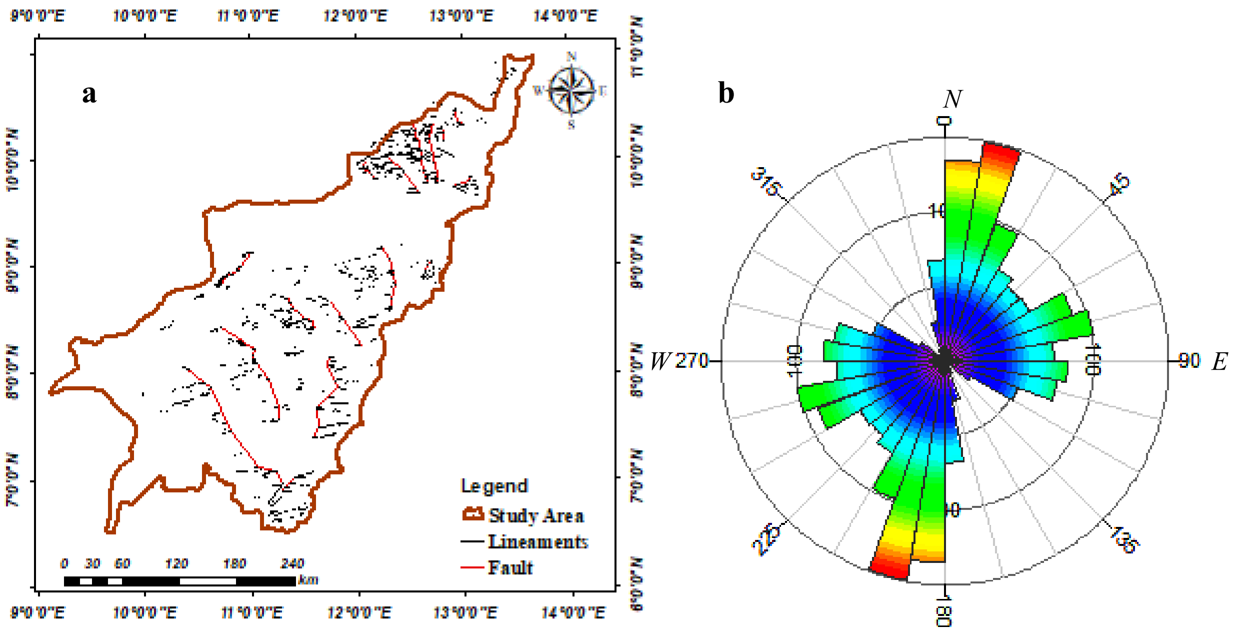

Figure 18:(a) Lineaments derived from the HGM in the study area Upper Benue Trough Northeastern Nigeria (b) Rose diagram reveals the dominant structural trends within the study area, with prominent orientations observed along the N-S and E-W directions, as well as subordinate trends along the NE-SW and NW- SE axes.

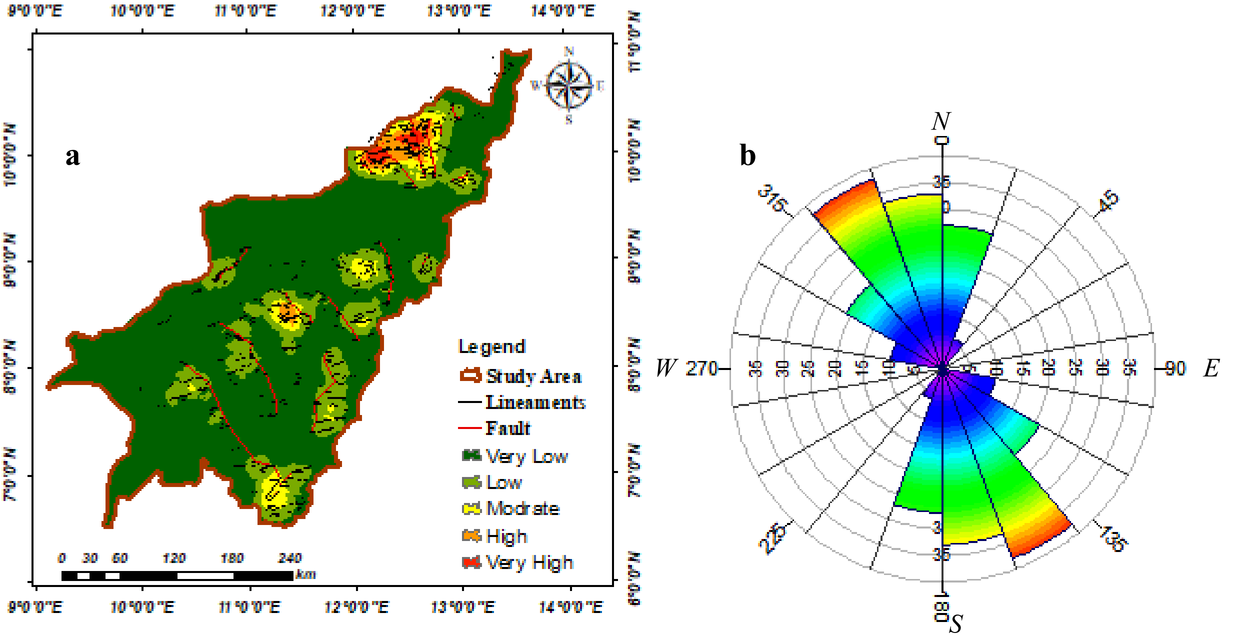

Figure 19:(a) Lineament density map and corresponding of the Adamawa-Taraba Region within the Benue Trough, derived from HGM analysis, (b) Rose diagram showing dominant NE-SW to ENE-WSW structural trends with subordinate NW-SE orientations, indicative of regional tectonic controls and fracture patterns.

Geohazard Implication Assessment

The relationship between structural lineaments and geohazards was evaluated by identifying zones of high lineament density and intersection frequency, which often represent tectonic (zones of weakness) within the crust (Ugwu & Alasi, 2016). These zones were further analyzed in relation to DEM and lineament density pattern to determine their susceptibility to erosion, landslides, and ground instability.

Interpretation focused on correlating DEM, FVD, and HGM-derived structural features with geohazard-prone zones such as:

i. Fault reactivation and seismic risk- areas of dense, intersecting lineaments in the northern and central part of the study area.
ii. Landslide susceptibility-high-gradient zones near uplifted basement blocks southeastern part of the study area.
iii. Flooding and subsidence- low FVD amplitude regions in the west central part of the study area with thick sedimentary cover and low structural relief.

CONCLUSION

This study demonstrates the effectiveness of integrating aeromagnetic and geospatial techniques for delineating subsurface structural lineaments and assessing geo-hazard susceptibility in the Adamawa–Taraba region of the Upper Benue Trough. The applied filters, particularly the First Vertical Derivative, Analytic Signal, Tilt Derivative, and Horizontal Gradient Magnitude, successfully enhanced structural features and revealed dominant NE-SW and NW-SE tectonic trends consistent with the regional geodynamic framework. The results indicate that high magnetic gradient zones correspond to uplifted and fractured basement terrains prone to fault reactivation, landslides, and localized seismicity, while low-gradient sedimentary regions are more susceptible to flooding, erosion, and subsidence. Lineament density and intersection analysis further identified structurally weak zones that act as pathways for fluid migration and zones of increased geo-hazard risk. Overall, the study confirms that aeromagnetic data, when integrated with DEM and GIS analysis, provides a robust and reliable tool for structural mapping and preliminary geo-hazard assessment. It is recommended that these findings be complemented with detailed geological, geotechnical, and hydrogeological investigations for effective hazard mitigation and sustainable land-use planning in the region.

ACKNOWLEDGEMENT

The author would want to sincerely thank Prof. Adetola Sunday Oniku and Prof. Bello Yusuf Idi my Ph.D Supervisors for providing expert guidance and academic support and to the Nigerian Geological survey agency (NGSA) and NASA making total magnetic intensity aeromagnetic data and S SRTM DEM data available for this study.

REFERENCES

Abdulsalam, N. N., Ogoh, E. K., & Ologe, O. (2022). Aeromagnetic investigation of subsurface structures in the Benue Trough, Nigeria.

Ahmed, Z. (2018). Geophysical interpretation of high-resolution aeromagnetic data of part of southwestern Nigeria for subsurface mapping (Doctoral thesis). Ahmadu Bello University.

Ajakaiye, D. E., Hall, D. H., Ashiekaa, J. A., &Udensi, E. E. (1986). Aeromagnetic anomalies and tectonic trends in and around the Benue Trough, Nigeria.

Ajakaiye, D.E., (1986). Structures Deduced from Gravity data in the middle Benue Trough. Nigeria Journal of African Earth. 5, 359.

Bello, R., et al. (2022). Structural analysis of high-resolution aeromagnetic data over parts of Gongola Basin, NE Nigeria.

Benkhelil, J. (1989). The origin and evolution of the Cretaceous Benue Trough, Nigeria. *Journal of African Earth Sciences*, 8(2–4), 251–282.

Blakely, R.J. (1995). Potential Theory in Gravity and Magnetic Applications. Cambridge: Cambridge University Press.

Cooper, G.R.J., & Cowan, D.R. (2006). Enhancing potential field data using filters based on the local phase. *Computers & Geosciences*, 32(10), 1585–1591.

Dike, E.F.C. (1993). Stratigraphy and structure of the Gongola Basin, northeastern Nigeria: Implications for petroleum exploration. *Journal of Mining and Geology*, 29(2), 171–180.

Esri Inc. (2011). ArcGIS (Version 10.6). Esri Inc. https://www.esri.com/en-us/arcgis/products/ar

Fairhead, J. D., & Green, C. M. (1989). Controls on rifting and basin formation in Africa and South America. *Tectonophysics*, 163, 1–14

Grauch, V. J. S., Hudson, M. R., & Minor, S. A. (2009). Aeromagnetic expression of fault systems and mineralized belts in southern New Mexico and western Texas. *Geosphere*, 5(5), 598–621.

Ibraheem IM, Elawadi EA, El-Qady GM. (2018). Structural interpretation of aeromagnetic data for the Wadi El Natrun area, northwestern desert, Egypt. J Afr Earth Sci. 139:14–25. https://doi.org/10.1016/j.jafrearsci.2017.11.036.

Ijeh, I. B., et al. (2019). Integration of aeromagnetic and Landsat data for lineament mapping in Milligan PR, Gunn PJ. (1997). Enhancement and presentation of airborne geophysical data. AGSO J Aust GeolGeophys. 17(2):63–75

Li, X. (2006). Understanding 3D analytic signal amplitude. *Geophysics*, 71(2), L13–L16.

Ma, G., & Li, L. (2013). *Alternative local wavenumber methods to estimate magnetic source parameters*. Exploration Geophysics, 44(4), 264–271. https://doi.org/10.1071/EG13010

MacLeod, I.N., Jones, K., & Dai, T.F. (1993). 3-D analytic signal in the interpretation of total magnetic field data at low magnetic latitudes. *Exploration Geophysics*, 24(4), 679–688.

Milligan, P., & Gunn, P. (1997). Derivative filters in aeromagnetic data interpretation. *Geophysics*, 62(3), 904–915.

Miller HG, Singh V. 1994. Potential feld tilt-A new concept for location of potential feld sources. Journal of Applied Geophysics. 32(2–3):213–217. https://doi.org/10.1016/0926-9851(94)90022-1

Nabighian, M.N. (1972). The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: Its properties and use for automated anomaly interpretation. *Geophysics*, 37(3), 507–517. https://doi.org/10.1190/1.1440276.

NASA Shuttle Radar Topography Mission (SRTM) (2013). Shuttle Radar Topography Mission (SRTM) Global. Distributed by OpenTopography. https://doi.org/10.5069/G9445JDF. Accessed 2026-04-10

Obaje, N.G. (2009). *Geology and Mineral Resources of Nigeria*. Berlin: Springer-Verlag.

Obaje, N.G., Wehner, H., Scheeder, G., Abubakar, M.B., &Jauro, A. (2006). Hydrocarbon prospectivity of Nigeria's inland basins: From the viewpoint of organic geochemistry and organic petrology. *AAPG Bulletin*, 90(3), 325–353.

Olade, M. A. (1975). Evolution of Nigeria's Benue Trough (aulacogen): A tectonic model. *Geological Magazine*, 112(6), 575–583.

Olatubosun, E. O., et al. (2022). Interpretation of aeromagnetic data for basement configuration in the Middle Benue Trough. Nigeria.

Opara, A. I., Onwuemesi, A. G., &Anudu, G. K. (2014). Analysis of aeromagnetic data over part of the Upper Benue Trough, northeastern Nigeria, using filters and source depth estimation techniques. *Environmental Earth Sciences*, 73, 7019–7032.

Oruç B, Keskinsezer A. (2008). Structural setting of the northeastern Biga Peninsula (Turkey) from tilt derivatives of gravity gradient tensors and magnitude of horizontal gravity components. Pure and Applied Geophysics. 165 (9–10):1913–1927. https://doi.org/10.1007/s00024-008-0407-8.

Petters, S.W. (1978). Stratigraphic evolution of the Benue Trough and its implications for the upper Cretaceous paleogeography of West Africa. *Journal of Geology*, 86(3), 311–322.

Phillips, J.D.(2000). Locating magnetic contacts: A comparison of the horizontal gradient, analytical signal and local wave number methods: 70th Annual International Meeting, SEG, Calgary Canada, Expanded Abstracts. 402-405.

Popoff, M. (1988). Du Gondwana à l'Atlantique Sud: Les connexions du fossé de la Benoué avec les bassins du Nord-Est brésilienjusqu'àl'ouverture du Golfe de Guinée. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, 12(1), 1–43.

Reid, A.B., Ebbing, J., & Webb, S.J. (2014). Avoidable Euler errors – the use and abuse of Euler deconvolution applied to potential fields. *Geophysical Prospecting*, 62(5), 1162–1168.

Roest, W.R., Verhoef, J., & Pilkington, M. (1992). Magnetic interpretation using the 3-D analytic signal. *Geophysics*, 57(1), 116–125. https://doi.org/10.1190/1.1443174.

Salem, A., Blakely, R. J., Green, C., Fairhead, J. D., & Ravat, D. (2014). *Estimation of depth to top of magnetic sources using the local-wavenumber approach in an area of shallow Moho and Curie depth—The Red Sea*. Geophysics.

Salem, A., Williams, S., Fairhead, J.D., Ravat, D., & Smith, R. (2007). Tilt-depth method: A simple depth estimation method using first-order derivatives of magnetic data. *The Leading Edge*, 26(12), 1502–1505.

Shahverdi M, Namaki L, Montahaei M, Mesbahi F, Basavand M. (2017). Interpretation of magnetic data based on Tilt derivative methods and enhancement of total horizontal gradient, a case study: zanjan Depression. J Earth Space Phys. 43(1):101–113.

Thurston, J.B, & Smith, R.S (1997). Automatic conversion of magnetic data to depth, dip, and susceptibility contrast using the SPI (TM) method. Geophysics 62:807–813. https://doi.org/10.1190/1.1444190

Ugwu, G. Z., & Alasi, T. K. (2016). Depth to magnetic sources and structural interpretation using aeromagnetic data in Nigeria.

Verduzco B, Fairhead .JD, Green, C.M, & MacKenzie C. (2004). New insights into magnetic derivatives for structural mapping. The Leading Edge. 23(2):116–119. https://doi.org/10.1190/1.1651454.

Waheed H. M, Mahmoud H. E & Mohamed Elsadek M. S (2023). Structural lineament analysis of the Bir El-Qash area, Central Eastern Desert, Egypt, using integrated remote sensing and aeromagnetic data:Vol:.(1234567890) Scientifc Reports 13:21569 https://doi.org/10.1038/s41598-023-48660-x

Wright, J. B. (1968). South Atlantic continental drift and the Benue Trough. Nigeria.

Wright, J. B. (1981). Review of the origin and evolution of the Benue Trough in Nigeria. *Earth-Science Reviews*, 17(3), 239–249.