

GEOPHYSICAL INVESTIGATION OF SUBSURFACE MINERAL POTENTIALS IN KAGARKO LOCAL GOVERNMENT AREA OF KADUNA STATE FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT: A geophysical investigation was conducted to investigate subsurface structures and mineralization potential within kagarko local Government area of Kaduna state which is bounded by 7°–7.5°E and 9°–9.5°N. aeromagnetic map of the area was used and processed. Lineament analysis revealed dominant NE–SW and NW–SE structural trends, with dense intersections near Shakpere, Izom, Tafa, Gujeni, and Mpape, indicating zones of weakness favorable for mineralization and groundwater flow. Standard Euler deconvolution (SI=3) solutions delineated shallow sources (<100 m) around Shakpere, Izom, and Tafa, and deeper anomalies near Gujeni and Mpape, suggesting fault-controlled mineralization at varying depths. Residual Total Magnetic Intensity (TMI) anomalies corroborated these findings, with magnetic highs near Shakpere, Izom, and Tafa pointing to

mafic intrusions or dyke-like bodies, while magnetic lows around Gujeni and Mpape suggested hydrothermal alteration zones. Collectively, the results highlight structurally controlled mineral targets in proximity to villages, delineate promising exploration zones, and emphasize the importance of considering community impacts and environmental risks in future resource development.

Keywords: *Investigation, Subsurface, Mineral, Potential, Kagarko*

1. Introduction

The entire world has been experiencing some economic uncertainties due to variety of factors. These uncertainties have plunged many countries into economic turmoil, which makes many countries difficult to pay workers' salaries and also unable to execute some infrastructural developments. This scenario is also peculiar in Nigeria, which in recent times; the country had to go on excess foreign borrowing to pay salaries and also to finance her budget. With the current happenings, many researches asserted that the best way to get out of this economic mess is to embark on economic diversification (Garba et al., 2022). One of the ways of diversification is to embark on minerals exploration. Luckily enough, Nigeria is dominated by Precambrian basement complex rocks that are grouped into three divisions. They include igneous, metamorphic and sedimentary rocks. Both igneous and metamorphic rocks are crystalline in nature which constitute the Precambrian basement complex occupying areas starting from north central down to eastern part of Nigeria. The other parts of Nigeria like Sokoto basin, Bida basin. Niger delta, Anambra, Chad basin constitutes the Sedimentary basin with sediments varying in age from Cretaceous to recent (Uriah 2018). Oluwatoyin et al., (2020) reported that Migmatite–gneiss represents one of the three principal rock units within Nigeria's basement complex. The origin of these rocks remains debated, as researchers hold differing views. Unlike the more frequently studied schist belts, granites, and pegmatites, information on Nigeria's migmatite–gneiss is limited. This scarcity of data is likely due to its structural complexity, polycyclic evolution, and limited association with economically viable mineralization. Researchers estimate that Nigeria's mineral resources are valued at several hundreds of trillions of dollars, with the majority approximately 70 percent lying beneath the subsurface of Northern Nigeria (Udegbe, 2014). The most effective method for harnessing valuable mineral resources is through magnetic exploration. This technique can be conducted on land, at sea, or in the

air. In regions with challenging terrain, airborne magnetometer surveys are particularly advantageous, as they are cost-effective per kilometer and can be carried out at high speed. In an aeromagnetic survey, a magnetometer is mounted on an aircraft, which flies in a grid-like pattern over the target area at a specified altitude and spacing. These parameters determine the resolution of the collected data. As the aircraft traverses the area, the magnetometer records variations in the Earth's magnetic field. These variations form the basis for producing an aeromagnetic map, which highlights magnetic anomalies linked to subsurface rock formations (Garba et al., 2022). While most rocks possess some degree of magnetism, only those with significant magnetic mineral content generate notable anomalies. Sedimentary rocks generally exhibit the lowest magnetic content, whereas igneous and metamorphic rocks contain higher concentrations. Within sedimentary successions, anomalies may arise from basement rocks such as dykes and volcanic intrusions, or from geological processes like iron contamination and alterations associated with hydrocarbon migration. Nigeria currently relies heavily on crude oil as its primary source of revenue. This dependence is unsustainable: oil contributes to global warming through greenhouse gas emissions, contaminates land during exploration, and produces carbon monoxide through incomplete combustion. Moreover, oil reserves will eventually be depleted, and fluctuations in global oil prices pose serious risks to national income. These challenges underscore the urgent need for Nigeria to diversify and explore alternative sources of revenue to secure its economic future (Dobrin and Savit 1988). In order to diversify, exploration and sustainable exploitation of mineral resources become crucial in meeting the financial and economic demands since the region has been found to be characterized by complex geology, and being recognized for its significant potential potential mineral deposits (Ema et al., 2024). Subsurface investigations by several researchers revealed the existence of mineral bearing rocks of economic values in northern Nigerian states such as Plateau, Nasarawa, Kaduna, Zamfara, Sokoto and so on (Usman et al., 2024a). Kagarko being one of the 23 local government area of kaduna state, has been found by researchers to have been endowed with a lot of mineral. Salawu et al., (2018) carried out a research on the particle size analysis and mineral assay in Kagarko local government area of Kaduna State. They found iron ore deposit located in a village called Gujeni and its environs. They collected Samples from four pits (A, B, C, and D), each spaced 100 meters apart and at a depth of 3 meters. These samples were combined to form

a composite sample, which was subsequently crushed and pulverized. The results of the particle size analysis and mineral assay revealed that mineral phases including hematite, rutile, goethite, and others are evenly distributed across all sieve fractions, ranging from +355 μm to -50 μm . This minerals potential deposits showed that the area will be economically viable if these minerals are eventually explored and exploited; and this prompted the purpose of this research.

2.0 The Geology of the study area

Kagarko Local Government Area (LGA) is located at approximately $9^{\circ}27'0''\text{N}$ (9.4500°) latitude and $7^{\circ}41'0''\text{E}$ (7.6833°) longitude in southern Kaduna State, Nigeria. Kagarko Local Government Area (LGA) in Kaduna State is predominantly underlain by the Pan-African crystalline Basement Complex, a vast geological formation that characterizes much of north-central Nigeria. This Basement Complex is composed mainly of ancient granites, gneisses, and schists, which were formed during the Pan-African orogeny (about 600 million years ago). The terrain is typically rugged, with rocky outcrops and gently undulating plains, influencing both the soil quality and land use patterns in the area. It shares boundaries with Kachia LGA to the north, Jaba LGA to the east, Paikoro and Gurara LGAs of Niger State to the west, Tafa LGA of Niger State to the southwest, Bwari LGA of the Federal Capital Territory (FCT), and Karu LGA of Nasarawa State to the south (Afuwai et al., 2014). geological map of Kaduna State showing the study area is shown in figure 1

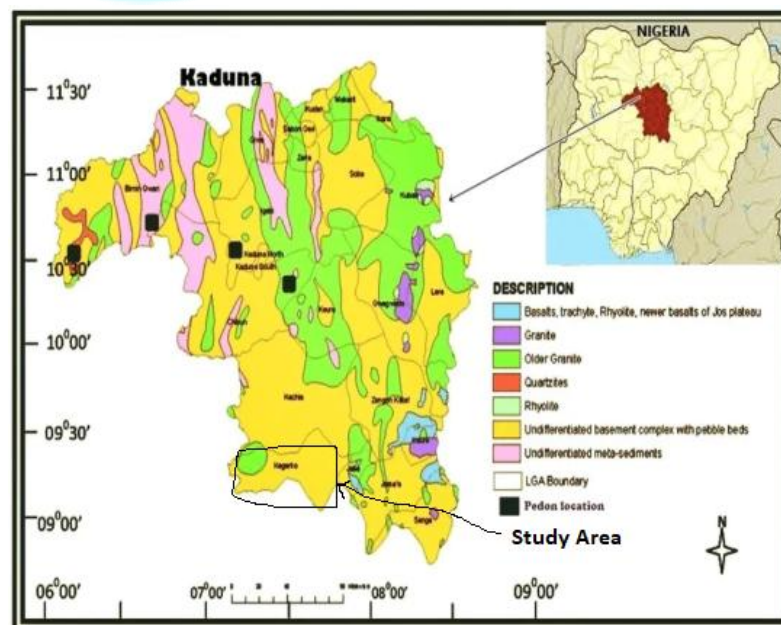


Figure 1: Geological Map of Kaduna State

3.0 Materials and Method

The materials used for this research work were aeromagnetic map, GPRS, Oasis montaj software, suffer, laptop. High resolution aeromagnetic data of Kagarko and its environs was acquired from the Nigeria Geologic survey Agency (NGSA). The data were obtained using a proton precision magnetometer with a resolution of 0.01nT. The aeromagnetic survey was flown at a line spacing of 500m at a map scale of 1:191035 series.

4.0 Data Processing

The method employed in this research was were enhancement methods to generate total magnetic intensity map (TMI), Regional map, Analytic signal map and 3D euler deconvolution map of the area. Total magnetic intensity (TMI) data measures variation in the intensity of the Earth's magnetic field causes by the contrasting content of rock-forming minerals in the earth crust. Magnetic anomalies can be either positive (field stronger than normal) or negative (field weaker) depending on the susceptibility of the rock.

4.1 Analytic Signal

The analytic signal is a filtering technique commonly applied in magnetic data interpretation. It is typically used in the frequency domain, producing maxima directly over discrete bodies and their edges. A key advantage of this method is that its amplitude is independent of the magnetization direction, making it particularly effective for delineating source geometry (Ansari and Alamdar, 2009). By generating a maximum value directly above the causative body, the analytic signal also facilitates depth estimation, which enhances its desirability in magnetic analysis (Ansari and Alamdar, 2009). The amplitude A of the analytic signal for the total magnetic field is calculated from the three orthogonal derivatives of the field. It is defined as:

$$|x, y| = \sqrt{\left(\frac{\delta f}{\delta x}\right)^2 + \left(\frac{\delta f}{\delta y}\right)^2 + \left(\frac{\delta f}{\delta z}\right)^2} \dots\dots\dots 1$$

A(x,y) is the amplitude of the analytical signal at (x, y), and ? is the observed magnetic field at (x,

y). Although the analytic signal is a derivative product which enhances magnetic fabric, apart from its above attributes, it has a mapping shortcoming in that two dimensional features often tend to break up into bull's eyes anomalies, and strike continuity is lost. However, the advantage of this magnetic data enhancement method is that its amplitude function is always positive and does not need any assumption of the direction of the body magnetization (Jeng et al., 2003).

4.2 First Vertical Derivative

Computing the first vertical derivative is a crucial step in interpreting aeromagnetic data, especially when analyzing narrow and shallow anomalies. This technique sharpens anomaly boundaries and highlights shallow features more distinctly. Compared to a total field intensity map, a first vertical derivative map is far more sensitive to local variations than to broad regional trends, producing a clearer and sharper representation. It is particularly effective for delineating high-frequency features that may otherwise be obscured by large-amplitude, low-frequency anomalies (Gunn, 1997).

4.2 Euler Deconvolution

The Euler Deconvolution method is a widely used technique in geophysics for interpreting magnetic data. It helps estimate the location and depth of magnetic sources automatically, making it valuable for identifying subsurface structures. The accuracy of depth estimation depends heavily on the structural index (SI), which represents the geometry of the source (e.g., sphere, dyke, fault) (Al-Badani and Al-wathaf , 2018). The structural index represents the scaling behavior of a magnetic source, derived from the principle of Euler homogeneity. It is defined as a fixed integer value, typically $n=1,2,3$, depending on the geometry of the source. The Euler Deconvolution equation can be expressed as:

$$(x - x_0) \frac{dT}{dx} + (y - y_0) \frac{dT}{dy} + (z - z_0) \frac{dT}{dz} = (B - T)n \dots\dots\dots 2$$

5.0 Results

The Total magnetic Intensity map of the study area is shown figure 2.

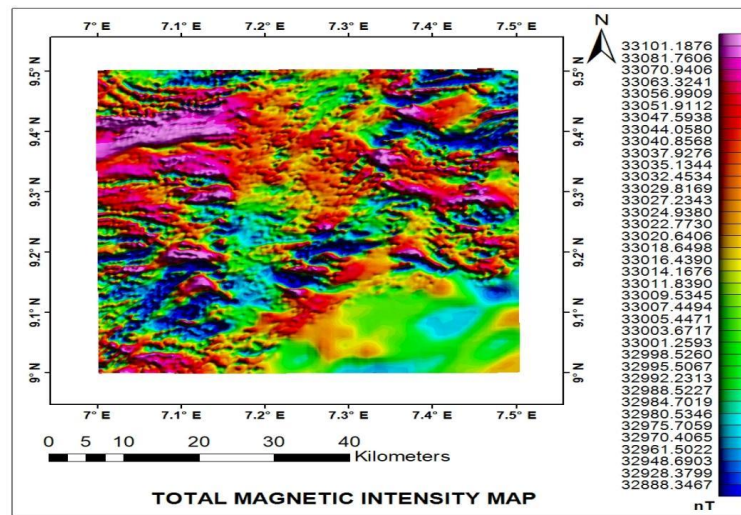


Figure 2: TMI of the Study Area

Figure 2 above is the Total Magnetic Intensity (TMI) map of the area which is always a key tool in mineral exploration. It shows variations in the Earth's magnetic field caused by differences in the magnetic properties of rocks. Areas with higher or lower magnetic intensity often indicate the presence of rocks rich in magnetic minerals (like magnetite) or structures that concentrate ore deposits.

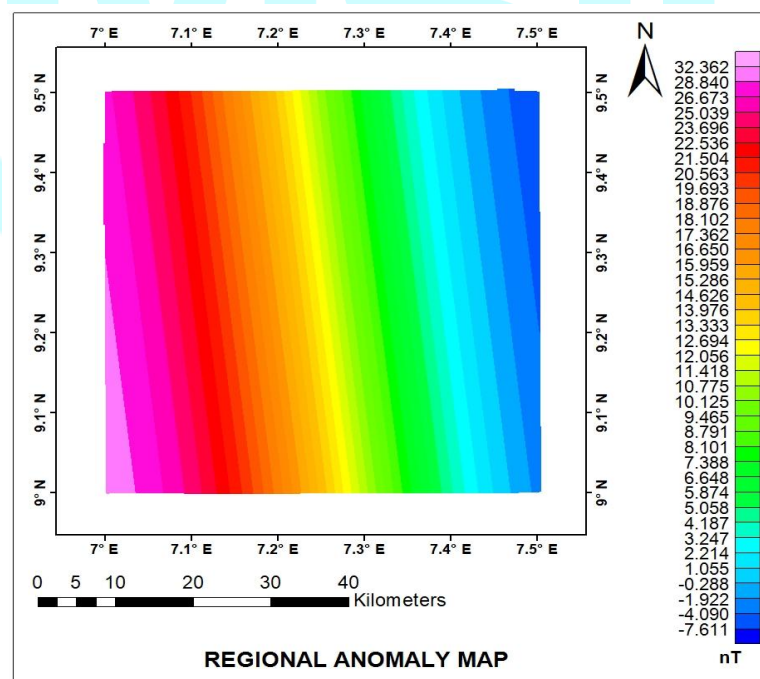


Figure 3: Regional Map of the Area

Figure 3 above showed a broad, large-scale magnetic trends across tens of kilometers which for identifying tectonic framework, major intrusions, and regional fault systems that are crucial in defining mineralized belts or corridors.

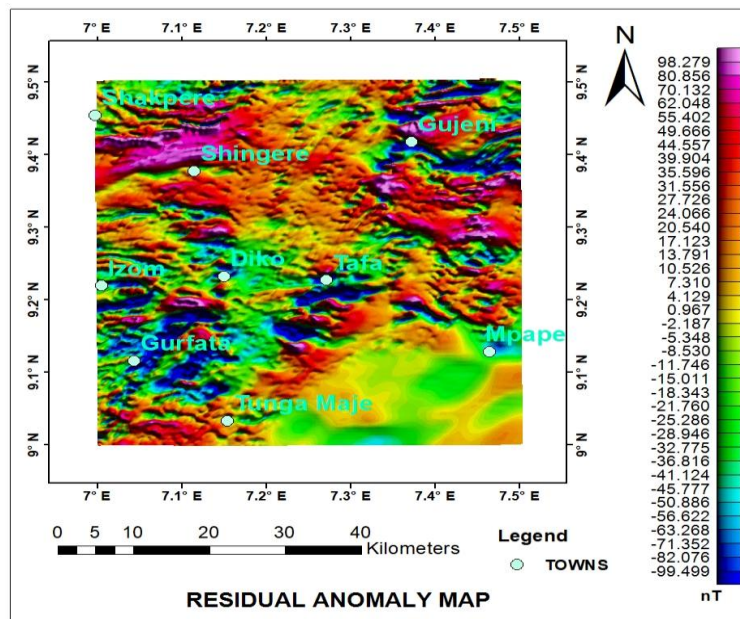


Figure 4: Residual Map of the Study Area

Figure 4 above displayed different areas with varying magnetic intensities. TMI (Residual Anomaly) map reveals distinct magnetic highs and lows across the area, which correlate with structural features and village locations. Strong magnetic highs (bright yellow zones) occur near Shakpere, Izom, and Tafa, suggesting mafic intrusions or dyke-like bodies that could host mineralization. Magnetic lows (purple zones) are more pronounced around Gujeni and Mpape, potentially indicating altered or sedimentary zones, often favorable for hydrothermal mineral deposits.

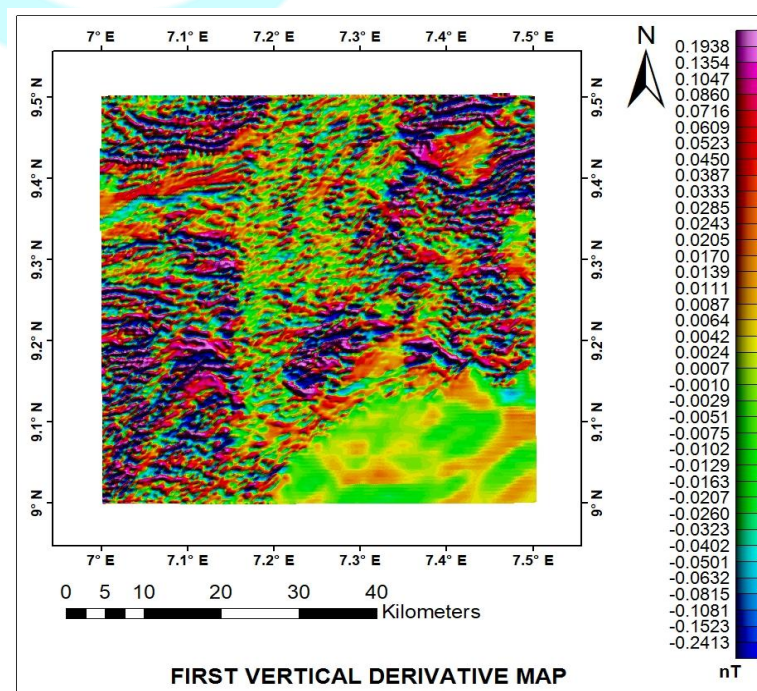


Figure 5: First Vertical Derivative Map of the Area

In order to sharpen the anomaly boundaries for tracing and locating faults, shear zones, and lithological contacts, first vertical derivative was applied. This helps in giving a clear picture of the subsurface conditions and consequently, define the geometry of ore-related bodies more precisely.

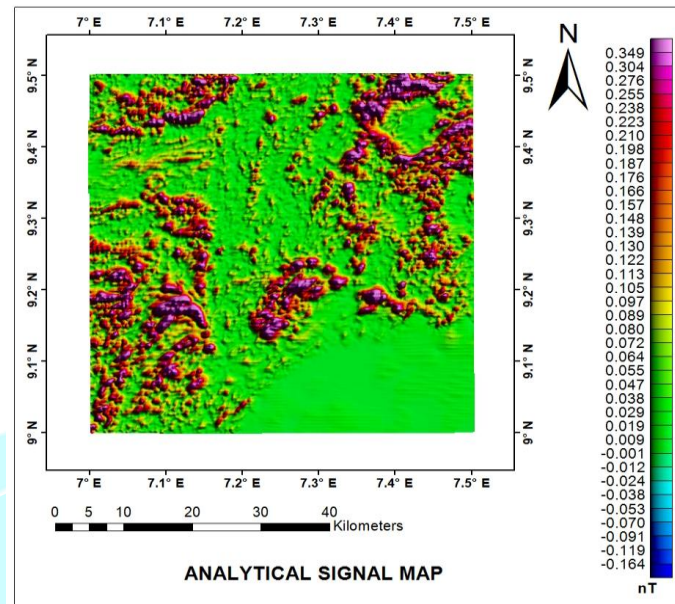


Figure 6: Analytical Signal Map of the Area

The figure above Pinpoints centers of anomalies, outlining ore body geometry. This one is particularly valuable because it highlights the edges and centers of magnetic sources regardless of their orientation, making it a powerful complement to the regional, residual, and FVD maps

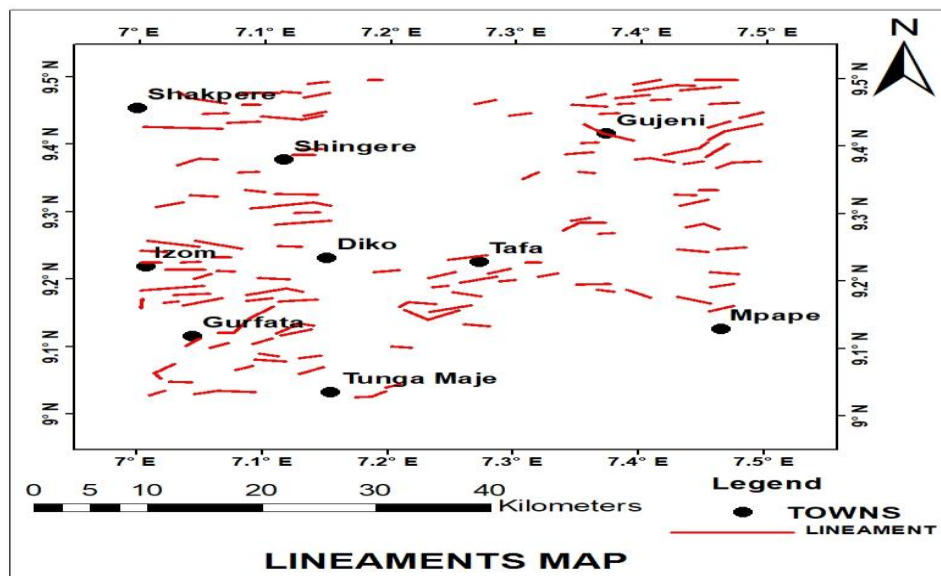


Figure 7: Lineaments map of the Area

The lineament map (figure 7) showed that most structures trend NE–SW and NW–SE, with dense clusters around towns like Shakpere, Izom, and Tafa. These zones of high lineament density and intersections, especially near Gujeni and Mpape, suggest areas of structural weakness that could host mineralization, as fractures often act as pathways for hydrothermal fluids. The alignment of settlements with these features also hints at hydrogeological significance, since lineaments can control groundwater flow and storage. Overall, the map highlights promising targets for mineral exploration, potential groundwater resources, and the need to consider environmental impacts if mining activities are pursued.

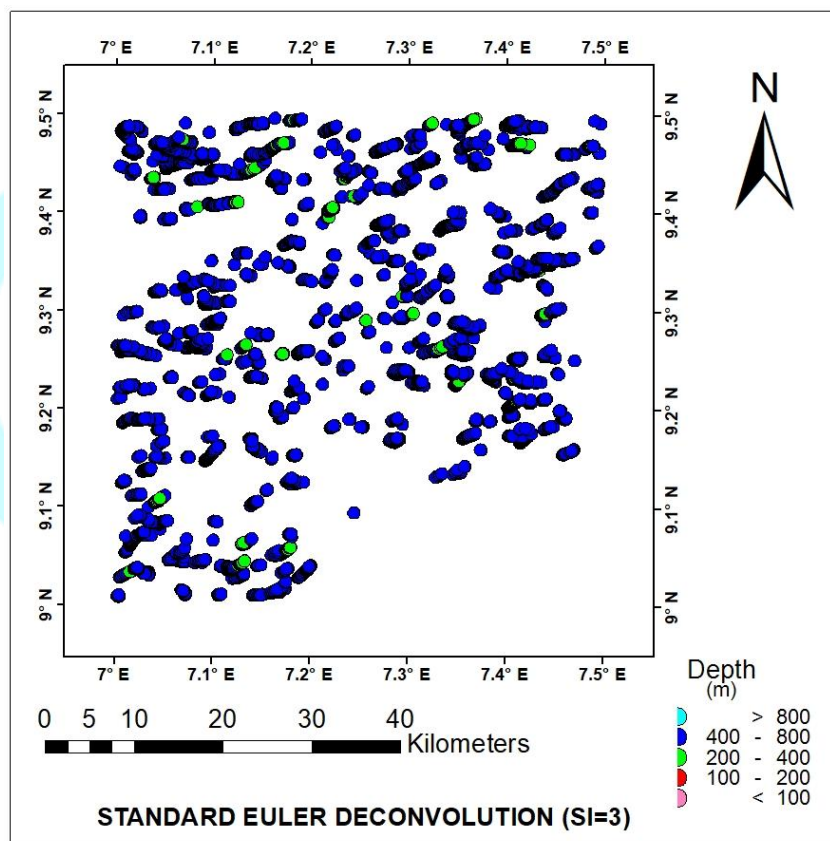


Figure 8: Standard Euler Deconvolution Map of the Area

The 3D Euler deconvolution map (SI=3) highlights subsurface sources consistent with dyke-like or fault structures. Shallow anomalies (<100 m, shown in red) are concentrated near villages such as Shakpere, Izom, and Tafa, suggesting zones of near-surface mineralization potential. Intermediate depths (100–400 m, pink and green clusters) occur around Gujeni and Mpape, aligning with lineament intersections and indicating deeper

structural controls that may host ore deposits. Deeper solutions (>400 m, blue to cyan) are more scattered, reflecting buried sources that are less immediately accessible but still geologically significant. Overall, the map suggests that villages located close to shallow and intersecting anomalies may sit near favorable mineral targets, while also raising the need to balance exploration opportunities with environmental risks and community considerations.

5.0 Conclusion

Lineament, Euler deconvolution ($SI=3$), and TMI residual anomaly gives a coherent picture of the subsurface geology and mineral potential of the area. The lineament map shows dominant NE–SW and NW–SE structural trends, with dense intersections near villages like Shakpere, Izom, Tafa, Gujeni, and Mpape, indicating zones of weakness favorable for mineralization and groundwater flow. The Euler deconvolution results highlight shallow sources (<100 m) near Shakpere, Izom, and Tafa, with deeper anomalies around Gujeni and Mpape, suggesting fault-controlled mineralization at varying depths. The TMI map reinforces these findings, with magnetic highs near Shakpere, Izom, and Tafa pointing to mafic intrusions or dyke-like bodies, while magnetic lows around Gujeni and Mpape suggest altered zones linked to hydrothermal activity. Taken together, the maps identify structurally controlled mineral targets near villages, highlight promising exploration zones, and underscore the importance of considering community impacts and environmental risks in future development.

Recommendations

From the findings of this research, the researchers wish to recommend that:

- i. Focus mineral exploration efforts around Shakpere, Izom, and Tafa, where shallow anomalies and magnetic highs suggest mafic intrusions or dyke-like bodies with strong mineral potential.
- ii. Conduct detailed geophysical and geochemical surveys around Gujeni and Mpape to better understand deeper, fault-controlled mineralization and altered zones linked to hydrothermal activity.

- iii. Evaluate groundwater flow potential in structurally weak zones near dense lineament intersections, as these areas may serve dual purposes for mineralization and water resource development.
- iv. Involve local communities in exploration planning near villages to ensure social acceptance, minimize disruption, and address environmental concerns.
- v. Implement baseline environmental studies and monitoring programs to mitigate risks associated with hydrothermal alteration zones and potential mining activities.
- vi. Combine aeromagnetic interpretation with other geophysical techniques (e.g., resistivity, gravity) and geological mapping to validate subsurface models and refine exploration targets.
- vii. Train geoscientists and exploration teams in advanced aeromagnetic data interpretation, particularly in using Euler deconvolution and derivative maps for structural analysis.

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