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Integrated geophysical methods for subsurface characterisation and health hazard assessment in parts of southwestern basement Nigeria

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Abstract. Aeromagnetic and radiometric data of Ikole Sheet 245 were interpreted for structural mapping, rock characterization and radionuclides hazard indices assessment. The data acquired were processed, filtered and enhanced to improve signal to noise ratio of rocks magnetisation. The Total Magnetic Intensity (TMI) map revealed high and low intensity values between 65 and 180 nT and -150 to -65 nT respectively. The residual map revealed clearer the undistorted signatures of the area geology and the interpretive boundaries of the underlying geology. Reduction to Magnetic Equator (RTE) map showed NE-SW regional lineament (R-R’) that diagonally divides the study area into approximately two equal halves; a central ridge between two depressions trending in NW-SE direction within Akoko complex and N-S faults of F1-F’1, F2-F’2 and F3-F’3 within Ikole axis. The upward continued maps (1 km, 2 km and 4 km) revealed the attitude of the basement rocks and structures with depth, some of the identified structures are deep-seated beyond 1.6 km downward, and as well revealed a general trend of NW-SE for the basement rocks. The radioelement maps revealed varying radioelement concentrations. Areas with high concentrations implied that the rocks are crystalline, undeformed and rich in feldspar with U-Th bearing minerals majorly within Ikole complex. Other regions with low concentrations on the other hand depicted varying geologic framework compositions. The maps also revealed uranium deposit in Ikole and mineralized structures such as veins, joints, fractures and dykes. The Ternary map showed that the two depressions (A) and deep-seated faults (F-F’) contain low and high radioactive rich bearing-minerals respectively. The spectral depth analysis result showed that the shallow and deeper magnetic sources have an average depth estimate of 20 m and 3.60 km respectively. The Absorbed dose and Annual effective dose equivalent (AEDE) of the study area are below the world standard limit for radiological hazard. Hence, the study areas are mineralized and have several structures that retain important radioactive minerals with no hazardous risk.

Keywords: Aeromagnetic, Aeroradiometric, Structural mapping, Radionuclides hazard indices, Magnetic sources

1. Introduction

Human existence and development has relied on natural resources obtained from both near surface and subsurface. Magnetic geophysical survey exploits the considerable differences in the magnetic properties of minerals with the ultimate objective of characterizing the earth’s subsurface. Magnetic survey method determines the subsurface spatial distribution of rock magnetization properties, (or susceptibility and remanence) which cause small changes in the earth’s magnetic field strength and...
Subsurface characteristics of interest to earth scientists include distribution and structure of rock types, grain size and rock strength, porosity, permeability and allowing decision making in assessing the risks and costs from subsurface information [1]. The physical principles of aeromagnetic methods are based on taking measurements of the ambient magnetic susceptibility of the surface geology and using the data to determine the distribution of magnetic minerals and changes in lithology [1]. High resolution aeromagnetic method has proved useful in mapping the basement structures and rapid selection of targeted areas for mineral exploration in Basement Complex of Southwestern Nigeria [2]. According to [3], the principles for the application of aeromagnetic surveys to geological mapping include the unique qualities of aeromagnetic data to comprise responses from magnetic minerals only, magnetic minerals are widely distributed in all terrains and the data are unaffected by non-magnetic cover, including vegetation, water and surficial deposits. The ability to accurately map a single geological parameter in a uniform manner over a very large area makes aeromagnetics highly suited to structural and lithological mapping over a wide range of scales [3].

Radiometric method involves the measurement of naturally occurring radioactive elements that exist in rock forming minerals and soil profiles. [4] indicated that airborne radiometric survey likewise is used to measure variations in the radioactive mineral composition in order to delineate lateral lithological changes. The decay products of radioactive elements such as uranium, thorium and isotopes of potassium are important in geologic mapping and mineral exploration [4]. Radioactive elements occur naturally in the crystals of particular minerals. Since the energy of gamma rays is related to the source radioactive element, they can be used to measure the abundance of those elements in an area. So by measuring the energy of gamma rays being emitted in an area, we can infer the presence of particular minerals in the earth’s surface. The gamma rays are detected by a spectrometer, which counts the number of times each gamma ray of particular energy intersects it [5; 6].

Radiometric survey is one of the most cost-effective and rapid techniques for geochemical mapping of the radioactive elements. Nowadays, the method is mainly applied for geological mapping and exploration of other types of economic minerals; geochemical and environmental monitoring such as mapping of radioactive contamination from fallout of nuclear accidents and plumes from power plants; allow the interpretation of regional features over large areas, and applicable in several fields of science [7; 8; 9]. They may be used to estimate and assess the terrestrial radiation dose permissible to human population and to identify areas of potential natural radiation hazard. The airborne datasets can provide detailed information about the characteristics of the soil and its parent geological materials, including surface texture, weathering, leaching, soil depth, moisture and clay mineralogy [10]. The ground survey provides opportunity to have direct access to take direct measurement on different rock types and to enhance signal to noise ratio than when measurements are taken few meters above the ground level. Gamma-ray have proved valuable in mapping the stratigraphy and structure of non-magnetic rock units, such as sedimentary and low-grade metasedimentary sequences, and for recognizing individual phases and zoning within units mapped out on the basis of differing K, Th and U concentrations. One of the most important recent applications of gamma-ray spectrometry is in the field of regolith-landform, soil, and land resource mapping, where it has been used to map geomorphic activity, regolith types, land degradation, soil types and soil loss [4].

Variation of magnetic and radiometric mineral composition in rocks as a result of the different lithological setting and mineralization processes like hydrothermal mineralization now form an integral part of most mineral exploration programs and form the basis of modern geological mapping most especially in basement terrain. High resolution gamma ray spectrometry, flown simultaneously with magnetics, is a cost effective mapping tool which provides a three-element- K, Th, U chemical map of the ground surface [11]. Gamma-ray data have proved complementary to magnetic data in many terrains, enabling mapping of bedrock and regolith in vegetated regions with an effective penetration, unlike remotely sensed data such as Landsat Thematic Mapper and SPOT Image, whose effective penetration is limited to the top few microns and masked by vegetation cover [12].

Increase failures of borehole development and other engineering projects such as roads, dams and bridges have prompted this study as a result of unpredictable depth to bedrock usually encountered in
basement terrains that is controlled by various geological factors. Hence, this study is designed to have detailed information about the characteristics of the subsurface towards decision making in predicting target areas for detailed exploration, environmental monitoring and estimate and assess the terrestrial radiation dose permissible to human.

2. Location and Geologic Setting of the Study Area

Ikole Sheet 245 is used as the study area for this research work. It lies within the Southwestern Basement Complex of Nigeria and lies within latitudes 7° 30’ N and 8° 00’ N (830000  – 885000 mN) and longitudes 5° 30’ E and 6° 00’ E (773500  – 830000 mE) of the Minna Zone 31 N (Figures 1 and 2). The towns in the study area include Ikole and other towns (Ekiti State) in the Northern to Western part; Ikare, Arigidi, Ajowa, and Akunu among others in Akoko area (Ondo State) at the Southern part, and Ayere to some parts of Kabba (Kogi State) situated within a small area at the Northeastern part. The areas are accessible mainly by roads and footpaths.

The Basement Complex of Southwestern Nigeria is located in a triangular portion of the Nigerian basement, an extension of the Dahomeyide shield of the West African Craton. Rocks of the region include Migmatized-Gneiss Complex (MGC) that is characterized by grey foliated gneiss, ultramafic rocks and felsic component comprised of pegmatite, aplite and granitic rocks [13]. The MGC in Southwestern Nigeria is affected by three major geotectonic events ranging from Early Proterozoic of 2000 Ma to Pan African events of ~600 Ma [14; 15; 16]. The rocks of the basement have been affected by medium pressure Barrovian metamorphism [16; 17]. The attitudes of tectonic structures in the Nigerian Basement have been documented in terms of orientation and magma-induced veins and dykes such as quartz veins and pegmatites [17]. Deformation of the Nigerian basement complex occurred in two phases, a ductile phase, which is responsible for the formation of planar structures (foliations) and a brittle phase resulting in jointing and fractures, many of which have been filled with quartzo-feldspathic veins, dolerite dykes, pegmatite and aplitic veins and dykes [17].

The major lithological units of the study area include the migmatites, granite gneiss, charnockite, granite, and other felsic and mafic intrusives. The basement rocks show great variations in grain size and in mineral composition. The rocks are predominantly quartz gneisses and schists (Ikole axis) consisting essentially of quartz with small amounts of white micaceous minerals. The rocks of the basement complex in the area have been subjected to intense regional metamorphism in which shearing stress was the dominant control resulting in the absence of minerals of high metamorphic grade. Magmatisation is widespread throughout the area reflected by rapid alternation of granite, biotite gneiss and biotite schist which grade into one another. Granite gneiss in the study area is of two types; the biotite rich gneiss and the banded gneiss. The biotite rich gneiss is fine to medium grained that show strong foliation trending westwards and is usually dark in colour. The banded gneiss show parallel alignment and alteration. Selective granitisation has resulted in biotite-rich layers in the gneisses being converted into porphyritic granite, while the leucocratic bands have been converted to aplitic granite. Minor folds are very common in the gneiss and schist of the study area [18; 19], the basic geological structure of Southwestern Nigeria is a complementary anticliriorium and synclinorium with northwards plunging axes.
3. Materials and Methods
Aero-geophysical data (total magnetic intensity and radiometric) covering Ikole Sheet 245 (1:100 000) were acquired from Nigeria Geological Survey Agency (NGSA), while the ground radioelements data were acquired within Akoko area using Gamma-Ray Spectrometer along eight (8) traverses (TR) taken on outcrops of granite-gneiss, charnockite, granite and grey-gneiss using a spread length of 100 m with spacing of 5 m between station positions. These aero-geophysical were processed using Oasis Montaj™ Software and Microsoft Excel Package.

The aeromagnetic TMI data (Ikole Sheet 245) within latitudes 7° 30’ N and 8° 00’ N (830000 – 885000 mE) and longitudes 5° 30’ E and 6° 00’ E (773500 – 830000 mE) of the Minna Zone 31 N is that of the total field and is in a gridded form. This method fits minimum curvature curves (which is the smoothest possible surface that would fit the given data values) using method described by [21]. The aeromagnetic data filtering and reductions commenced with the removal of the Near Surface Noise (NSN) caused by metallic materials, fences, cables (both buried and surface) and others using the Butterworth filter. The derived data after the removal of the NSN was reduced to the magnetic equator using the Reduction to Equator filter (RTE) with declination and inclination of -1.541° and -11.119° respectively, in order to centre the peaks of anomalies directly over their sources. Thereafter, the Regional Field associated with the measured magnetic data was produced to get the Residual data, by subtracting the derived Regional field data from the observed data (RTE). Other filtering process such as Upward Continuation to depth of 1, 2 and 4 km to see the attenuation of the high wave number anomalies and the accentuation of anomalies from deep-seated features was applied. Finally, the Residual map was divided into four Quadrants (1, 2, 3 and 4) and were windowed out to determine respective radially averaged power spectrum (depth analysis) used for depth to top of magnetic sources estimation.

The airborne radiometric gridded data from Nigerian Geological Survey Agency (NGSA), which have been corrected for aircraft noise and height attenuation, cosmic and background radiations removal, as well as stripping corrections derived from calibration data based on protocols described in [8] and [22 and 23] were imported into Oasis Montaj™ Software where appropriate filters were used to enhance signals attributed to important subsurface signatures and natural radioactivity. A Ternary map was also produced from same software after respective radioelements had been normalized (to an equal-area histogram) to annul the effect of potassium being the most crustal abundant radioactive elements from dominating and overriding other radioelements. [8] and USGS standard colour notation of red representing % K, green for eTh and blue for eU were used. Blue was used for eU because blue tends to reduce the poorest signal-to-noise ratio and accommodate the erratic nature of eU that would have been obvious to the eyes if other colours were to have been used.

The mean values of the ground radiometric data presented in Table 1 from eight (8) traverses were used to compute the mean values for Absorbed Dose Rate (D), Annual Effective Dose Equivalent (AEDE), and Internal and External Hazard Indices using standard equations. The results were displayed as bar plots for pictorial representations and compared with worldwide potential hazards index standard, in order to determine if rock materials sourced within the selected area is safe for people inhabiting the study area and for other construction purposes without posing any significant radiological health hazard.

The gamma radiation doses can be estimated by employing the convenient formula [24].

\[ D = (0.462\ C_U + 0.621\ C_{Th} + 0.0417\ C_K) \text{ nGy h}^{-1} \]  

(1)

where D is the absorbed dose rate in nGy h⁻¹, C_U, C_Th and C_K represent the activity concentrations of \(^{238}\text{U},^{232}\text{Th}\) and \(^{40}\text{K}\) respectively. It is assumed that the contribution from other radionuclides, such as \(^{137}\text{Cs},^{235}\text{U},^{89}\text{Rb},^{90}\text{Sr},^{138}\text{La},^{144}\text{Sm}\) and \(^{176}\text{Lu}\) to the total dose rate are negligible. UNSCEAR reported that the world average absorbed gamma dose rate mean is 55 nGy/h.

The annual effective dose equivalent (AEDE) received outdoor by a member of the public is calculated from the absorbed dose rate by applying dose conversion factor of 0.7 Sv/Gy and occupancy factor for outdoor and indoor was 0.2 and 0.8 respectively [25].
AEDE (Outdoor) (µSv/y) = D (nGyh) × T × Q × 0.2 × 10⁻³

where D is the absorbed dose rate in air, Q is the conversion factor of 0.7 Sv/Gy, which converts the absorbed dose rate in air to human effective dose received and T is the time for one year, i.e. 8760 hrs. The external (\(H_{ex}\)) and internal (\(H_{in}\)) radiation hazard indices were calculated respectively due to natural radionuclides of \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K. For the radiation hazard indices to be negligible, both the external (\(H_{ex}\)) and internal (\(H_{in}\)) radiation hazards must be less than unity [26]. Internal exposure to radon is very hazardous which can lead to respiratory diseases like asthma [27]. Natural radionuclide in soil, sediment and rocks produce an external radiation field to which all humans are exposed. Therefore, the \(H_{ex}\) and \(H_{in}\) indices were evaluated by using equations 4 and 5 respectively [28].

\[
\begin{align*}
H_{ex} &= \frac{C_{U}}{370} + \frac{C_{Th}}{259} + \frac{C_{K}}{4810} \leq 1 \\
H_{in} &= \frac{C_{U}}{185} + \frac{C_{Th}}{259} + \frac{C_{K}}{4810} \leq 1
\end{align*}
\]

where \(C_{U}\), \(C_{Th}\) and \(C_{K}\) are the radioactivity concentrations of \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K in Bqkg⁻¹ respectively. The elemental concentrations of Uranium-238 (in ppm), Thorium-232 (in ppm) and Potassium (in %) can be calculated from measured activity concentrations of \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K in Bqkg⁻¹ using the conversion factors recommended by [29] as follows:

\[
\begin{align*}
1 \text{ ppm} &= 10^{-4} \% \\
1 \% \text{ K} &= 313 \text{ Bq/kg of } ^{40}\text{K} \\
1 \text{ ppm U} &= 12.35 \text{ Bq/kg of } ^{238}\text{U} \\
1 \text{ ppm Th} &= 4.06 \text{ Bq/kg of } ^{232}\text{Th}
\end{align*}
\]

4. **Results and Discussion**

Generally, the maps are depicted as high – moderate – low magnetic intensity across the whole area. It is evident from the various maps produced that there are different rock types; infilled geologic materials from different degrees of weathering and movement of fluid along faults lines; anomaly trends and closures; structural features with depth from one location to another that brought about the separation of the study area into different complexes.

From the TMI map (Fig. 3), several deductions were made from the range of magnetic intensity variations for respective rock types and other geologic features in the study area. The map shows magnetic intensity of highs (55 – 180 nT) classified as undeformed crystalline basement rocks; magnetically quiet zones in greenish colour as zones marked to fall within the undeformed and zone of alteration (yellowish); and low to very low magnetic intensity (-150 to -40 nT) designated as highly susceptible materials, infilled geologic materials and fluid. The amplitude of a magnetic anomaly is directly proportional to magnetization which depends on magnetic susceptibility of the rocks; the high and low magnetic susceptible areas on the TMI maps are depicted as low and high magnetic intensity values respectively, and a low/negative magnetic peak values represent typical anomalous signatures [11; 30; 31]. The total magnetic intensity varies from one complex to the other due to the mineral contents of rocks and level of geological processes such as fractures, weathering, etc.

The colour shaded Reduction to the Magnetic Equator (RTE) (Fig.4) map shows rocks of low intensities caused by high degree of deformation and weathering, classified as migmatite and other minor rock types with large numbers of intrusive rocks. Also, a NE-SW trending regional lineament (R- R') that diagonally divides the study area into approximately two equal halves and a central ridge
between two depressions trending in NW-SE direction within Akoko complex are revealed on this map. The RTE map clearly reveal the N–S faulting system in Ikole complex to be a normal faults of F1-F’1, F2-F’2 and F3-F’3, contributing to the identified low magnetic intensities in this area.

The Residual map (Fig. 5) gives a clearer and undistorted signatures of the study area geology from which the interpretive/inferred boundaries on the geological map (Fig. 2) are being proper delineated relative to their positions, based on different complexes, variations in the compositions of the crystal lattices framework, degree of weathering and metamorphism, separating the study area into three complexes namely; Ikole complex at the northwestern to southwestern part, Akoko complex from the southwestern to northeastern part and Kabba complex as a small complex on the northeastern part of the map. The map also reveals the presence of faults, lineaments and other structures.

![Figure 3. Total Magnetic Intensity (TMI) Map](image-url)
Figure 4. Colour Shaded Reduction to Magnetic Equator (RTE).

Figure 5. Residual and Delineated Boundaries Map of the Study area.

Figures 6a, b and c show the upward continued maps to 1 km, 2 km and 4 km respectively, in order to accentuate the responses from the basement rocks/deep-seated features that are useful in the interpretation of magnetic anomaly fields over areas containing many near surface magnetic sources.
such as dykes and other intrusions. The maps reduce ambiguities in the earlier identified litho-
structures with depth. The upward continuation maps reveal a regional NW-SE trend for the rocks in
the study area. The mapped faults within the Ikole complex, the two large depressions formed on both
sides of the NW-SE trending ridge within Akoko complex and the NE-SW regional lineament are
deep-seated because they are seen to be far beyond 1 km (Fig. 6a). The identified faults appear to be
less than 2 km in depth (Fig. 6b), while other features are seen beyond this depth, even the depressions
are far beyond 4 km (Fig. 6c). It was inferred that the intense metamorphism that brought about high
fracturing density and degree of weathering in the area are pronounced in rocks around Akoko and the
structures associated with these processes also deep-seated. It is also established that the deep sources
could be attributed to basement and intra-basement features like lineaments/faults, dykes and veins.

Figures 7 show the eU (Fig. 7a), eTh (Fig. 7b) and K (Fig. 7c) concentrations maps respectively. The
eU concentration map (Fig. 7a) depicts moderately high to very high eU concentration ranging from
4.5 – 13.0 ppm mostly where the faults were identified around Ikole and as low to very low ranging
from -1.5 to 3.0 ppm mostly around Akoko and Kabba areas. The eTh concentration map (Fig. 7b)
evines somewhat similar radioactivity patterns and variations as observed in some sections of the eU
map. High eTh concentration ranged from 25.0 – 70.0 ppm, with dominance around the fault zones in
Ikole and some areas in Akoko, while the low eTh concentration ranged from 8.5 – 16.0 ppm and very
low (< 8.5 ppm) dominating Kabba and some of the rocks around Akoko areas. The % K concentration map (Fig. 7c) on the other hand shows high % K radiation ranging from 2.0 – 4.0 %
over a wide area extent around Ikole, especially where the faults occurred and within some areas
around the southern part, while very low % K (< 0.7 %) radiations are seen around the central, western
and eastern part of the study area.

The areas with moderately high to very high radioelements concentrations could be described as
undeformed rocks with uranium, thorium (such as thorite, zircon) and potassium rich bearing-
minerals. The low areas are considered to be infilled geologic materials or fluids within the host rocks
cauised by pronounced geological processes such as weathering, fracturing and also that the veins,
Joints, lineaments and faults may not contain radioactive rich minerals that could have given off high
radioactivity. On the eU concentration map, high radioactive emission rate around and along the N-S
trending faults around Ikole area confirms the presence of a deep-seated uranium deposit associated
with other radioactive elements. These maps also reveal the strike directions of the rocks, generally in
NW-SE direction with fewer rocks trending NE-SW and E-W. Interestingly, radioactive responses of
various rock types in the study area have helped in lithological differentiations; mapping of the faults
and regional lineament features; rate of weathering, and identify areas that contain radioactive rich
bearing-minerals.

The Ternary map for the three (3) radioelements concentrations (Fig. 8) is produced for proper
summary and to show the dominance of respective radioelements contributions in various geologic
materials. In areas where we have black (denoted as A) and white (denoted as B) colourations indicate
that the three radioelements concentrations are low and high respectively, while other colourations
(denoted as C, D and E) may suggest variations in radioelements concentrations or level of radiation
by one or two radioactive elements. The two depressions on both side of the ridge (delineated in green
polygonal line) around Akoko reveal accumulated geologic materials of low radioactivity, while the
ridge contains minerals rich in U, Th and K. The Ternary map also reveals NE-SW regional lineament
trend (R–R’) separating the complexes, deep-seated faults (F–F’) rich in radioactive minerals with high
spontaneous emission and various geological boundaries.

The radially averaged power spectrum plots (Fig. 10) were produced from four quadrants (Fig. 9) to
infer the total depth estimate to top of magnetic sources that produced the observed anomalies in the
study area using spectral analysis. The gradients of the layers were calculated at two different points as
shallower and deeper sources based on the wavelength of magnetic sources. The gradients are:
Quadrant 1 (0.5 and 20.0), Quadrant 2 (0.47 and 5.5), Quadrant 3 (0.25 and -20.0) and Quadrant 4
(1.75 and 45.0) with approximate depth estimate. The calculated depths are: Quadrant 1 (40 m and 1.6
km), Quadrant 2 (37 m and 440 m), Quadrant 3 (20 m and 1.6 km) and Quadrant 4 (140 m and 3.6 km)
respectively. The total depth estimates to top of magnetic sources for shallower and deeper sources are 20 m and 3.60 km respectively.

Figures 6. Upward continuation maps for (a) 1 km, (b) 2 km, and (c) 4 km
Figures 7: Radioactive Concentration Maps of Uranium (a), Thorium (b), and Potassium (c)
Figure 8. Ternary Map of Study Area showing the distribution of radioelements concentrations.

Figure 9. TMI showing quadrants selected for Radial Average Power Spectrum.
Figure 10. Radial Average Power Spectrum Plots of selected quadrants for depth estimation.

The results of the Total Mean values for eU, eTh, % K, Dose rate, Absorbed and Effective Dose Rates for ground radiometric survey are shown in Table 1. The mean values were computed from field data and those calculated using standard equations through Microsoft Excel. From Table 1 and Figure 11, variations in radioelements from the ground survey were seen to vary from one lithology to another i.e. from traverses (TRs) 1 to 8. TR 4 has the highest eU, eTh and % K; TR 5 has the lowest % K; while, TR3 with the lowest eU and eTh. TR4 responses could be used to infer that the rocks are crystalline, undeformed and rich in feldspar, U - and – Th – bearing minerals. TRs 3, 5, 6, 7 and 8 depict varying geologic framework compositions, degree of metamorphism and weathering in various rocks. From the ground radiometric survey, it is evident that the rocks around Akoko area of this study have undergone intense deformation than other parts. Its worthwhile recording the gamma-ray exposure/dose levels obtained from the survey data to deduce some certain parameters for the hazard indices. The mean ground-level dose rates obtained for different traverses varied approximately from 96.5 to 130 (nGy/h). Figures 12 and 13 show the pictorial representation plots for the mean Absorbed Dose Rate (D) and Annual Effective Dose Equivalent (AEDE) for outdoor/external human index radiological hazard, with TR 1 having highest values, TR 3 has the lowest of all, while other traverses have nearly same values. The highest mean Absorbed Dose (16.1 nGy/h) in the study area is below the background cosmic rays value of 55 nGy/hr (Nano Gray per hour) [24]. Also, the highest mean Annual Effective Dose Equivalent (AEDE) value of about 19.75 µSv/y (micro Sievert per year) (i.e.0.01975 mSv/y) is far below the worldwide effective dose of 2.4 mSv/y [24], and below the minimum permissible limit of 1 mSv/y recommended by [32]. The health hazard impact assessment for both external and internal
radiations to human reveal values below unity Therefore, radiations from the investigated areas are radiologically hazard risk free to people living in the study area.

Table 1: Mean Values of Radionuclides emitted from respective traverses

| LOCATION | K (%) | eU (ppm) | eTh (ppm) | K (Bq/Kg) | U (Bq/Kg) | Th (Bq/Kg) | Absorbed Dose Rate (D) (nGy/h) | AEDE (µSv/y) | H_ex | H_in |
|----------|-------|----------|-----------|-----------|-----------|-----------|-------------------------------|--------------|-------|-------|
| TR1      | 3.78  | 3.2      | 23.95     | 1183.14   | 97.24     | 16.51     | 20.25                         | 0.728        | 0.835 |
| TR2      | 2.45  | 3.94     | 21.85     | 766.85    | 88.71     | 15.50     | 19.00                         | 0.633        | 0.765 |
| TR3      | 3.26  | 2.57     | 15.02     | 1020.38   | 31.74     | 10.65     | 13.06                         | 0.533        | 0.619 |
| TR4      | 3.82  | 6.85     | 30.05     | 1195.66   | 84.60     | 21.99     | 26.96                         | 0.948        | 1.176 |
| TR5      | 2.07  | 4.07     | 20.50     | 647.91    | 83.23     | 14.70     | 18.03                         | 0.592        | 0.727 |
| TR6      | 2.21  | 3.37     | 23.74     | 691.73    | 96.38     | 16.39     | 20.10                         | 0.628        | 0.741 |
| TR7      | 2.39  | 3.13     | 20.97     | 748.07    | 85.14     | 14.57     | 17.87                         | 0.599        | 0.693 |
| TR8      | 2.48  | 3.34     | 20.48     | 776.24    | 83.15     | 14.36     | 17.62                         | 0.593        | 0.705 |

Figure 11. Activity concentration of radionuclides of the study area
5.0 Conclusion

High resolution airborne interpretation of Ikole Sheet 245 have shown the robustness of using integration methods that is further complemented by ground survey in characterizing magnetic intensities; radioelements concentrations and distributions of eU, eTh and % K; effective mapping of lithologies and geological structures such as fractures, lineaments, faults and dykes with their trends; depth to magnetic sources; radiological impact risk assessments and amount of dose rate permissible to human.

The maps produced for this study revealed some rocks/materials with different range of magnetic intensities and susceptibilities, radioactivity, some infilled geologic materials based on amplitude variations, structural trends of approximately N–Sand a regional lineament trending NE–SW
directions. These variations could be attributed to geologic materials, crystal lattices framework and mineral compositions of various rock types in the study area. Interestingly, it is evident from the different magnetic reduction maps such as RTE, upward continuations, spectral depth estimation of 3.6 km, radioelements concentrations (eU, eTh and % K) and Ternary maps, that the faults are deep-seated and host uranium deposit with other rich radioactive bearing-minerals. The lineament is regional and extends into Kabba complex. The complexes have been highly deformed and weathered, most especially the Akoko and Kabba complexes which showed intense deformations that had restructured the rocks by folding and creating high fracturing density with both smaller and elongated lineaments in them. Points of the deep fractures in the area would be important hydrogeologically for groundwater development. In addition, the Ikole Complex comprises rocks that have granitic crystal framework compositions making the area to be less deformed and the veins and faults within some of the rocks are mineralized. The geology of Ikole Complex is quite different from their counterparts in Akoko and Kabba complexes of the study area. The Absorbed Dose, AEDE and the external hazard (H_{ex}) and internal hazard (H_{in}) indices have values that are below the world standard limit for radiological hazard in humans. Therefore, the study areas pose no risk to humans inhabiting there or in nearby areas.

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