Neewaj Journal of Multidisciplinary Research & Innovations
ISSN: 3108-3404 | Open Access | CC BY 4.0

Vol. 2, Issue 2, Apr-Jun
Year: 2026

Research Paper

Delineating Potential Hydrocarbon Targets in the Anambra Basin Through Aero-Radiometric Techniques

Bello YA[1], Ndom BN[1], Egahi S[1]

[1]Physics/Electronics Department, Air Force Institute of Technology, Kaduna

Received: 01 May 2026 **Accepted:** 13 June 2026 **Published:** 20 June 2026

Abstract

This study delineates prospective hydrocarbon accumulation zones in the Anambra River area using Delineation of Radiometric Anomalies (DRAD) and normalized aero-radiometric data. High-resolution airborne gamma-ray data of potassium (K), thorium (Th), and uranium (U) were processed using ternary maps, isotope ratios, and the Simplified Thorium Normalization Method (STNM) to reduce surficial and lithological effects. The results revealed characteristic hydrocarbon signatures, particularly low normalized potassium and high normalized uranium values, which identified three potential hydrocarbon-bearing locations. These locations also recorded positive DRAD values, further indicating hydrocarbon accumulation. The study demonstrates the effectiveness of radiometric methods as a cost-effective, non-invasive tool for preliminary hydrocarbon exploration and highlights their importance in frontier basin evaluation.

Keywords: Anambra River, Radiometric data, Hydrocarbon, DRAD

Introduction

The global demand for hydrocarbons as a primary energy resource continues to drive the search for new frontier basins and innovative exploration techniques. Traditional approaches to hydrocarbon prospecting—such as seismic reflection, gravity, and magnetic surveys—have historically provided insights into subsurface structural configurations and sedimentary basin geometries. However, the increasing complexity of frontier basins, coupled with the high cost and logistical constraints associated with conventional geophysical methods, has created a need for complementary, cost-effective, and high-resolution techniques. In this context, airborne radiometric surveys, particularly those focusing on the distribution and normalization of natural radioelements, have emerged as powerful tools in delineating regions with enhanced hydrocarbon potential.

The Anambra Basin, located in southeastern Nigeria, represents a prominent Cretaceous sedimentary depocenter that has attracted considerable interest due to its petroleum system potential. The basin forms part of the larger Benue Trough system and is characterized by thick successions of marine and deltaic sediments deposited during multiple transgressive–regressive cycles associated with the opening of the South Atlantic. Despite significant hydrocarbon discoveries in adjacent basins such as the Niger Delta, exploration in the Anambra Basin has been relatively limited. This is partly due to the structural complexity of the basin, as well as the limited

DOI: https://doi.org/10.5281/zenodo.20780911

application of non-seismic geophysical methods that could provide complementary insights into its petroleum system framework. Against this backdrop, delineating prospective hydrocarbon regions in the basin through advanced aero-radiometric analysis represents both a methodological innovation and a practical necessity.

Airborne radiometric surveys measure the gamma-ray emissions of naturally occurring radioelements—potassium (K), uranium (U), and thorium (Th)—within the upper few tens of centimeters of the Earth's surface. Although originally developed for geological mapping and mineral exploration, radiometric data have more recently been applied in hydrocarbon exploration with growing success. Hydrocarbons migrating toward the surface can induce subtle geochemical and mineralogical alterations in overlying sediments, a phenomenon commonly associated with microseepage. These alterations often manifest as changes in clay mineralogy, oxidation–reduction processes, and redistribution of radioelements. For example, zones of hydrocarbon seepage have been shown to correspond to localized depletion or enrichment of K, U, and Th concentrations, creating radiometric anomalies that can be mapped from airborne surveys. Several studies (e.g., Darnley, 1997; Grasty, & Multala, 1991; IAEA, 2004; Ajakaiye et al., 2010) have reported that such anomalies, when normalized to minimize background lithological effects, provide valuable proxies for identifying hydrocarbon-related alteration zones.

The technique of normalization—where the ratios of radioelements such as Th/K, U/K, and U/Th are employed—has proven especially effective in distinguishing hydrocarbon-related anomalies from those due to lithological variations or weathering processes. These ratios reduce the influence of absolute abundance variations and enhance the detection of subtle geochemical signatures. In regions like the Anambra Basin, where diverse lithologies coexist, normalization is critical to isolating signals that may be diagnostic of hydrocarbon microseepage. Furthermore, the application of Differential Radiometric Anomaly Delineation (DRAD) enhances interpretability by accentuating anomalies relative to local background levels, thereby allowing for a more robust mapping of prospective zones.

The mapping of hydrocarbons through radiometric methods has been demonstrated across various geological settings worldwide. In the Western Canadian Sedimentary Basin, radiometric surveys have successfully delineated hydrocarbon seepage zones linked to petroleum accumulations in Devonian and Cretaceous reservoirs. In India's Krishna-Godavari Basin, integration of radiometric anomalies with geochemical soil gas surveys improved predictions of hydrocarbon-prone zones. Similarly, studies in the Gulf of Mexico and the Middle East have shown that radiometric signatures, when combined with magnetic and gravity datasets, yield enhanced models of petroleum prospectivity. Despite these successes, the application of radiometric methods in Nigerian basins remains limited, with most exploration continuing to rely heavily on seismic methods.

Within the Anambra River region, the integration of DRAD with normalized radioelement data offers an underexplored but promising pathway for hydrocarbon exploration. The riverine environment presents both a challenge and an opportunity: challenges due to sediment reworking and alluvial cover, and opportunities owing to its role in focusing sedimentary deposition and potential hydrocarbon migration pathways. By employing a systematic approach that normalizes radioelement concentrations and delineates differential anomalies, it becomes possible to highlight zones of potential hydrocarbon enrichment that may not be readily visible through conventional methods alone.

This study, therefore, seeks to delineate prospective regions for hydrocarbon accumulation in the Anambra River area using DRAD and normalization of aero-radiometric data. By leveraging the high-resolution coverage of airborne gamma-ray surveys and applying advanced data transformation techniques, the research aims to establish a framework for integrating radiometric methods into hydrocarbon exploration workflows in frontier basins. Ultimately, the findings are expected to contribute not only to the understanding of the Anambra Basin’s petroleum system but also to the broader discourse on the role of non-seismic geophysical methods in modern hydrocarbon exploration

Geology of the study area

The Anambra Basin, a Late Cretaceous foreland basin formed following the Santonian uplift of the Abakaliki Anticlinorium, which created accommodation space for marine, deltaic, and fluvial sediment deposition (Reyment, 1965; Nwajide, 2013). The basin contains key petroleum-bearing formations, including the organic-rich Nkporo Formation, the coal-bearing Mamu Formation with significant source rock potential, and the highly porous and permeable Ajali Sandstone, which serves as an excellent reservoir rock (Obaje, 2009; Nwajide, 2013). The combination of these source and reservoir units, together with the basin's relatively simple structural setting, indicates favourable conditions for hydrocarbon generation and accumulation.

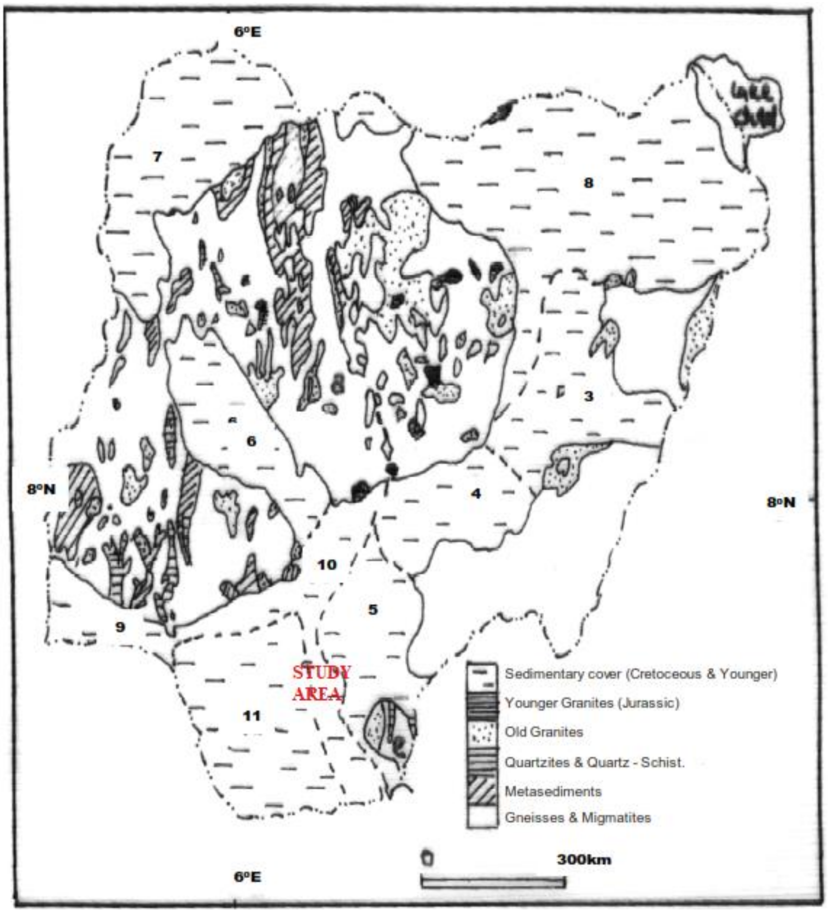


Figure 1. Geology of Nigeria including the study area (Nyekuru et al., 2013)

Material and Method

The primary material is the radiometric data of the study area. Airborne radiometric data used in this study. The data was sourced from the Nigerian Geological Survey Agency (NGSA) Abuja, Nigeria. The data were acquired at an altitude of 100 m along with a flight line spacing of 500 m oriented in NW-SE and a tie line spacing of 2000 m. The maps are on a scale of 1:100,000 and half-degree sheets.

The methodology employed radiometric data (K, eU, and eTh) processing and analysis to identify potential hydrocarbon-related anomalies in Ibaji and Aguleri. After preprocessing, including leveling, micro-leveling, and background correction, the data were gridded and mapped to reveal the spatial distribution of radionuclides. Qualitative interpretation was carried out using ternary and isotope ratio maps, while quantitative assessment involved profile analysis and statistical evaluation of elemental concentrations. Potassium and Uranium values were normalized against Thorium using the Simplified Thorium Normalization Method (STNM) to minimize lithological and surficial effects and enhance hydrocarbon-related signatures. Finally, Delineation of Radiometric Anomalies (DRAD) was performed using statistical thresholds based on mean and standard deviation values to identify and map anomalous zones with potential hydrocarbon significance.

DRAD was determined using the equations below

$$\mathrm{DR}AD = eUD\% - KD\% \tag{1}$$

$$KD\% = \frac{(Ks - Ki)}{Ks} \tag{2}$$

$$eUD\% = \frac{(eUs - eUi)}{eUs} \tag{3}$$

$$Ki = \left(\frac{mean\ Ks}{mean\ eThs}\right) eThs \tag{4}$$

$$Ui = \left(\frac{mean\ Us}{mean\ eThs}\right) eThs \tag{5}$$

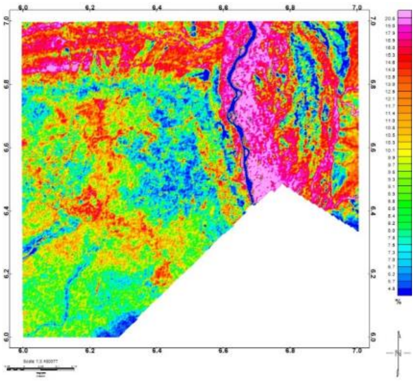
where eTh is the actual thorium value and Ui is the calculated equivalent thorium-defined uranium value for that station. A detailed information about the method is contained in Bello *et al.* (2024).

Result and Discussion

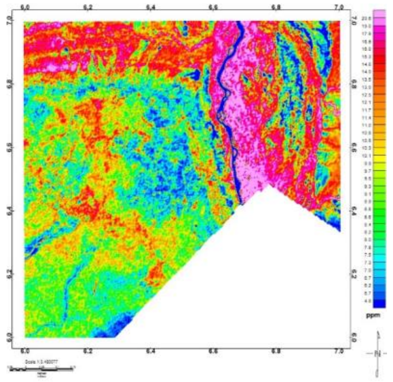
The shale-rich, organic-bearing formations and reservoir rocks in Ibaji and Aguleri suggest strong petroleum potential. Variations in uranium, thorium, and potassium within these rocks can be detected by gamma-ray spectrometry, aiding subsurface lithological mapping and identification of hydrocarbon indicators. Thus, understanding the geological framework is vital for radiometric-based hydrocarbon exploration (Bierwirth, 1997; C. A. Kogbe, 1989)

Buried hydrocarbon deposits can create surface radiometric anomalies through micro-seepage, bacterial activity, groundwater movement, and chemical changes such as redox and pH variations (Bello et al., 2024). Over time, these processes alter the physical, chemical, and biological properties of near-surface rocks and soils, often resulting in reduced potassium, thorium, and uranium concentrations in oil-producing zones due to enhanced leaching by hydrocarbon-related groundwater acids (Bello et al., 2024).

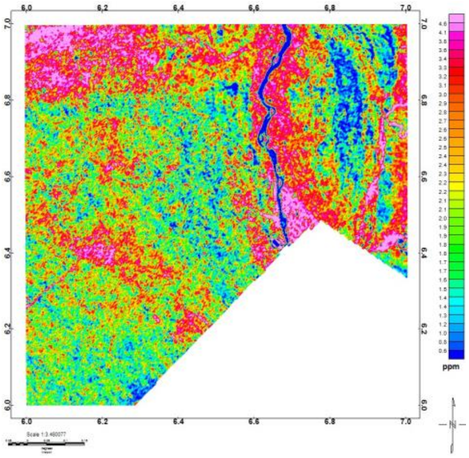
The spectrometric map showing the variations of the concentrations of the three radioelements within the study area was produced (Fig. 2).



(a)



(b)



(c)

Fig 2. Spectrometric map showing the variation of (a) potassium (b) thorium (c) uranium concentration in the study area.

Uranium mobility depends on its valence state: soluble U^{6+} can migrate to the surface through hydrocarbon-related micro-seepage and is later reduced to immobile U^{4+} by organic compounds. Hydrocarbon-generated acidic groundwater also alters clay minerals, releasing potassium and influencing its distribution. These interactions among uranium, potassium, and thorium create distinct surface radiometric patterns above hydrocarbon accumulations, making geophysical mapping effective. In particular, oil-producing zones are often characterized by low normalized potassium and high normalized uranium values relative to thorium.

The ratio maps of potassium and uranium with respect to thorium are an interesting pointer to the presence of hydrocarbon in certain locations. OPZ exhibit a significant and characteristic anomaly; low normalized potassium and high normalized uranium value. These were observed in the normalized maps of the study. This known characteristic was then used to identify locations with potential for hydrocarbon accumulation; thus, three locations were notable (Fig 3).

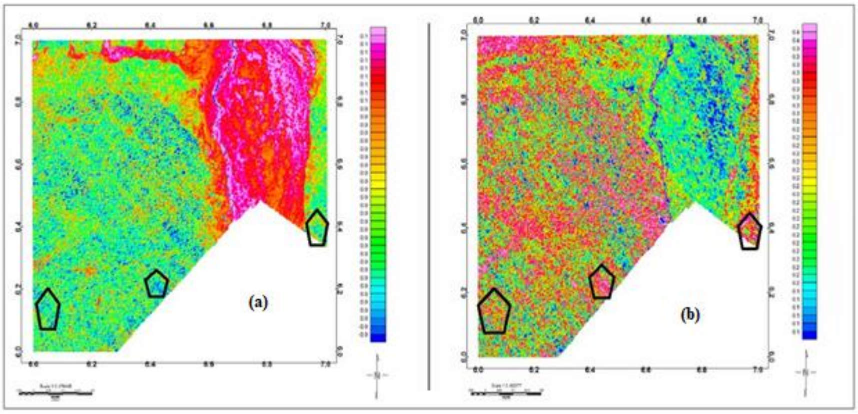


Fig. 3. Maps indicating locations with promising hydrocarbon accumulation based on the normalization of (a) Potassium and (b) Uranium with Thorium

DRAD technique was then used to confirm the viability of the three identified locations for hydrocarbon accumulations. Interestingly, the three locations of the Anambra Basin recorded positive DRAD values (see Fig. 4), a pointer to hydrocarbon accumulation.

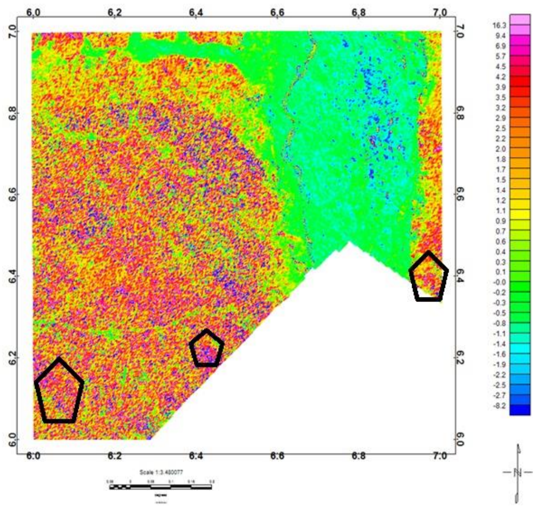


Fig 4. DRAD map of the study area showing three promising locations for hydrocarbon accumulation.

Conclusion

The radiometric survey of Anambra produced encouraging results, with multiple methods consistently identifying three probable hydrocarbon accumulation zones. Analysis of uranium, thorium, and potassium distributions revealed anomalies linked to lithological variations and possible hydrocarbon-bearing formations. In particular, low uranium and potassium with elevated thorium suggest geochemical alteration associated with hydrocarbon migration or organic-rich shales. These findings highlight the petroleum potential of the study areas, narrow exploration targets to reduce cost and risk, and establish gamma-ray spectrometry as an effective preliminary tool for guiding further investigations such as seismic surveys and drilling.

Funding Statement

This research received no external funding.

References

- Ajakaiye, D. E., Uko, E. D., & Onwuemesi, A. G. (2010). *Geophysical mapping of Nigeria's inland basins. Nigerian Association of Petroleum Explorationists.*
- Bello Y.A., Mohammed B.Y. and Muhammad A.B. (2024). Delineating Potential Hydrocarbon Targets Through Aero-Radiometric Techniques. *PHYSICSAccess,* 04(02), 116-125. https://doi.org/10.47514/phyaccess.2024.4.2.014
- Bierwirth, P. N. (1997). *Evaluation of airborne gamma-ray spectrometry for mapping soil and regolith properties*. *AGSO Journal of Australian Geology & Geophysics, 17(2), 129–135.*
- Grasty, R. L., & Multala, J. (1991). *Monitoring environmental radiation using airborne gamma-ray spectrometry*. *Journal of Environmental Radioactivity, 14(1), 41–54. https://doi.org/10.1016/0265-931X(91)90046-U*
- International Atomic Energy Agency (IAEA). (2007). *Guidelines for radioelement mapping using gamma ray spectrometry data. IAEA-TECDOC-1363. Vienna: IAEA.*
- Kogbe, C. A. (1989). *Geology of Nigeria (2nd ed.). Lagos: Rock View Nigeria Ltd.*
- Nwajide, C. S. (2013). *Geology of Nigeria's sedimentary basins. Lagos: CSS Press.*
- Obaje, N. G. (2009). *Geology and mineral resources of Nigeria. Berlin: Springer*
- Obaje, N. G., Wehner, H., Scheeder, G., Abubakar, M. B., & Jauro, A. (2004). *Hydrocarbon prospectivity of Nigeria's inland basins: From the Dahomey to the Chad Basin. Journal of Petroleum Geology, 27(1), 5–27.*
- Onyekuru S.O., Onu N.N., Iwuagwu, Nwankwor C. J., G.I., Ukaonu C.E. (2013). Dispersal Patterns of the Late Cretaceous to Early-Tertiary Sediments in the Southern Anambra Basin, Southeastern Nigeria. *International Journal of Geosciences,* 4, 588 – 604. doi:10.4236/ijg.2013.43054
- Reyment, R. A. (1965). *Aspects of the geology of Nigeria: The stratigraphy of the Cretaceous and Cenozoic. Ibadan University Press.*