ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-5035 (Print)
ISSN: 2521-5043 (Online)
CODEN: ESMACU

Earth Sciences Malaysia (ESMY)

DOI: http://doi.org/10.26480/esmy.02.2024.151.157

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RESEARCH ARTICLE

STATISTICAL ANALYSIS OF RADIOELEMENTS DISTRIBUTION OVER PARTS OF SOUTHEASTERN NIGERIA USING CORRELATION METHOD

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ARTICLE DETAILS

Article History:

Received 09 February 2024
Revised 12 March 2024
Accepted 22 April 2024
Available online 25 April 2024

ABSTRACT

Statistical analysis using correlation method was carried out on radiometric data in some parts of South-eastern Nigeria. The objective was to assess the spatial relationships and potential correlations among various radioactive elements in the designated area. The study area spans latitudes 5°001' N to 6°301' N and longitudes 7°001' E to 8°301' E, covering approximately 27,225 km². Utilising the superspectrometer RS 230, a comprehensive survey was conducted. Parameters including uranium, thorium, and potassium were measured. Radiometric data analysis and interpretation unveiled the mean concentrations of uranium (U), thorium (Th), and potassium (K) in the study area, registering at 3.02 ppm, 11.22 ppm, and 0.43%, respectively. These values align closely with the standard averages of 2.973 ppm, 11.084 ppm, and 1.342%, respectively. This examination sheds light on the distribution and levels of radionuclides within the surveyed region, contributing to a deeper understanding of its geological composition and potential implications. Statistical analysis revealed an R^2 value of 0.730 between Uranium and Thorium. The value obtained is above 0.5 showing a good relationship between the two. This also indicates that their concentrations are dependent on each other in the study area. But R^2 values obtained between Uranium and Potassium is 0.006 and between Potassium and Thorium is 0.004 which are both less than 0.5. This depicts a weak relationship between the concentrations of Uranium and Potassium, and between Potassium and Thorium. This in turn revealed that the concentrations of the both sets in the study area are independent of each other.

KEYWORDS

Radiometrics, Radioelement, Uranium, Thorium and Potassium

1. Introduction

Radiometrics, also known as Gamma ray spectrometry, is a specialized geophysical technique. It is primarily used to estimate the concentrations of specific radio-elements, namely potassium, uranium, and thorium (Knight et al., 2021). This is achieved by measuring the gamma rays that these elements emit during the process of radioactive decay. Gamma ray spectrometry proves to be an effective tool in various applications (Momčilović et al., 2012). In the geological environment, it serves as a mapping tool, helping scientists understand the distribution and concentration of these radio-elements (César de Mello et al., 2021; Weihermann et al., 2021; Abangwu et al., 2023). It is also used in locating and characterizing radioactive environmental contamination, providing crucial data for environmental protection efforts.

The concentrations of uranium, thorium, and potassium are known to vary sympathetically in many geological materials. This means that changes in the concentration of one element often correspond to changes in the concentrations of the others (Taufiq et al., 2020; Lawal et al., 2023). For instance, in some regions of southeastern Nigeria, there is a preferential enrichment of potassium relative to both uranium and thorium (Faruwa et al., 2021; Nwokeabia et al. in 2023). The distribution of these radio-elements is largely dependent on the distribution of the rocks from which they originate (Mohanty et al., 2004; Aboelkhair and Zaaeimah, 2012). However, certain geological materials exhibit selective concentrations or depletion of each of these elements. Despite this, the total gamma radiation resulting from the radioactive decay processes of uranium, thorium, and potassium is often sufficient to indicate the type of rock (Ahmed in 1998).

Certain atomic nuclei spontaneously disintegrate, emitting alpha, beta, and gamma radiation, transforming into other elements (Akpan et al., 2020; Weihermann et al., 2021). This process, known as radioactivity, is used for exploration purposes, particularly gamma radiation due to its superior penetration power. Uranium, thorium, and potassium isotopes are significant for exploration (IAEA, 2003). The primary objective of this work is to assess the degree of interdependence and relationship between the distribution of these radio-elements. The findings will have practical applications in several fields. These include mineral exploration, where understanding the distribution of these elements can guide prospecting efforts; environmental monitoring, where changes in their distribution can signal potential contamination; and geophysical and geological studies, where predictions about the presence and concentration of specific radio-elements can inform our understanding of various geological formations.

2. Location of the Study Area

The study area of interest is strategically located within the southeastern Nigerian Cretaceous sedimentary basins. This region, which spans

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Cite The Article: Nwokeabia Charity Nkiru, Opara Alex Iheanyichukwu, Omenikolo Ibe Alexander, Eluwa Ndidiamaka Nchedo, Agoha Chidiebere Charles (2024). Statistical Analysis Of Radioelements Distribution Over Parts Of Southeastern Nigeria Using Correlation Method. *Earth Sciences Malaysia, 8(2): 151-157.*

latitudes from 5°00'N to 6°30'N and longitudes from 7°00'E to 8°30'E, is depicted in Figure 1. The basins cover an expansive area of approximately 27,225 km^2. They stretch from the northern city of Enugu to Uyo in the south, and from the communities of Orsu and Ikot Ekpene in the east and west, respectively.

This region is not just geographically significant but also holds immense geological and cultural importance. It contributes substantially to a broader understanding of Nigeria's diverse landscape and history. The geological formations and cultural heritage of this area provide a rich tapestry of information that enhances our comprehension of Nigeria's complex past and present (Akaolisa and Selemo, 2009). The study of these basins, therefore, offers valuable insights into the geological evolution and cultural history of southeastern Nigeria. This makes the region an important focus for researchers and scholars interested in Nigeria's geology and cultural heritage.

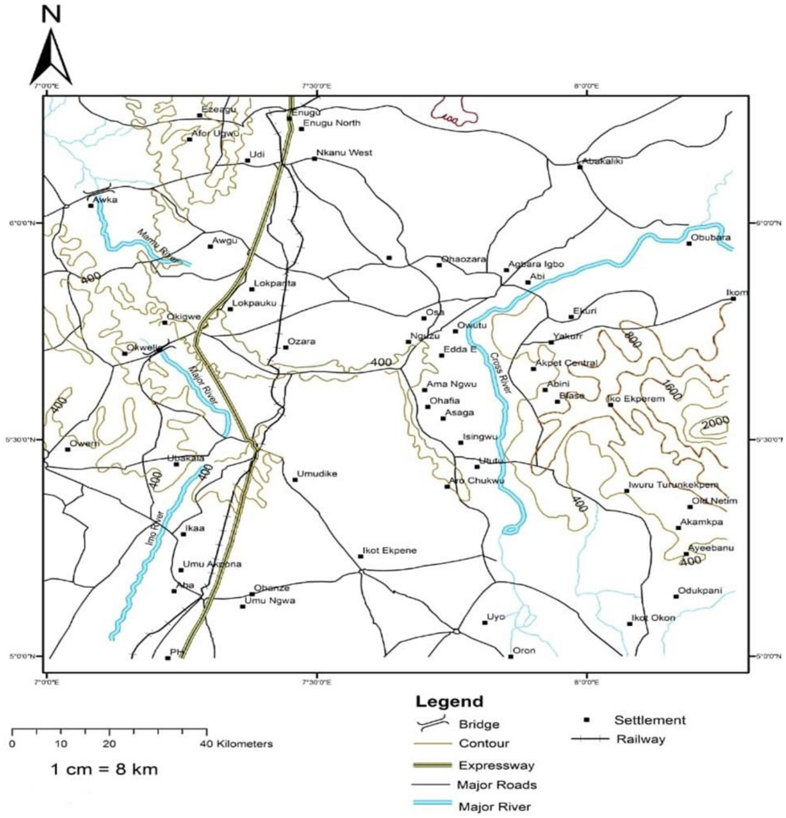

Figure 1: Location Map of Study Area

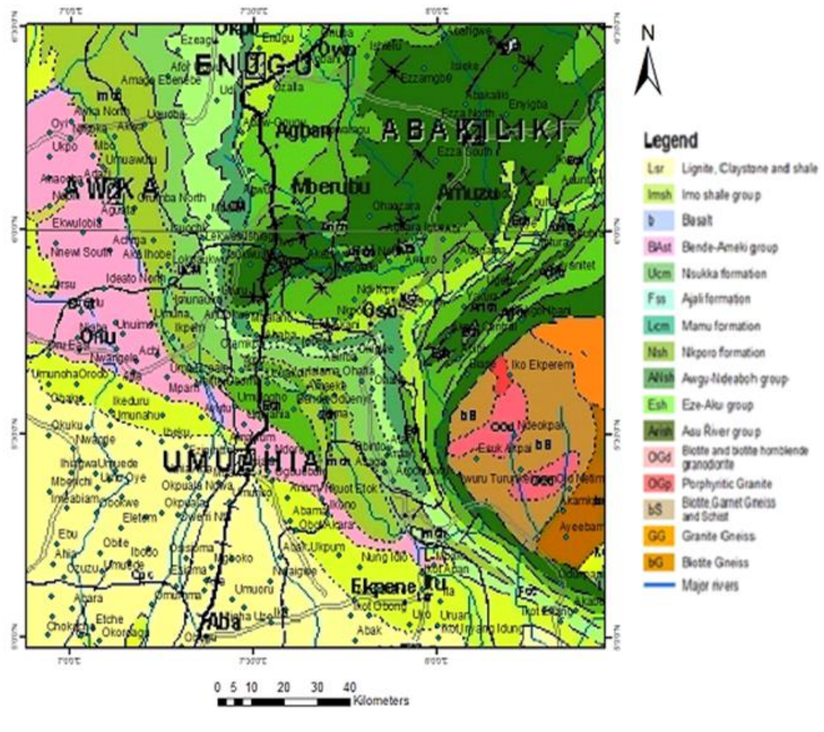

Figure 2: Geology map of the study area

Numerous academics have extensively researched and documented the geological history of southeastern Nigeria (Peters, 1978; Carter et al., 1963; Cratchley and Jones, 1965; Offodile, 1976). These studies have shed light on the region's complex geological processes and transformations.

The structural activity in this region began during the Coniacian period and reached its peak in the Santonian era. During this time, the Benue-Abakaliki Trough underwent an uplift, leading to the formation of the Abakaliki Anticlinorium along a northeast-southwest axis, as illustrated in Figure 2. This structural inversion led to the creation of depressions on both sides of the anticlinorium. The smaller Afikpo Sub-basin was formed to the southeast, and the larger Anambra Basin was formed to the northwest.

The area had three separate sedimentary basins from the Companian to the Paleocene periods. These were the Anambra Basin, the Afikpo Sub-basin, and the Abakaliki High, which was in between the two basins (Selemo and Akaolisa, 2010; Ehujuo et al., 2017).

Peters provides a comprehensive account of the area's stratigraphy and sedimentological history, detailing the various layers of rock and the history of sediment deposition in the region (Peters, 1978). The primary factors influencing sedimentation in the trough were global eustatic sea-level fluctuations and basin tectonics. These geological processes have played a significant role in shaping the landscape of southeastern Nigeria.

The study of these processes and their effects on the landscape provides valuable insights into the geological evolution of the region. It also contributes to our understanding of the broader geological history of Nigeria and the African continent. The knowledge gained from these studies is crucial for various applications, including natural resource exploration and environmental management.

3. Methodology

The spectrometric survey was conducted using a handheld RS-230 BGO Spectrometer. This device is recognized as the industry standard for portable gamma ray surveys in geophysical applications. The RS-230 BGO Spectrometer is designed with an integrated system that includes a large detector and data storage capabilities. It is built to withstand all weather conditions, making it a reliable tool for fieldwork. One of the key features of the RS-230 BGO Spectrometer is its high sensitivity, which ensures accurate readings. It is user-friendly and equipped with Bluetooth (BT) connectivity. This feature allows for a wireless connection to Bluetooth-enabled devices such as an external GPS receiver, earphone, or computer, enhancing its functionality and ease of use.

The survey was meticulously carried out along roads and footpaths, with stations spaced 500 meters apart. This systematic approach ensured comprehensive coverage of the area. The primary parameters measured during the survey were uranium, thorium, and potassium levels. These elements are commonly measured in geophysical studies due to their radioactive properties and their abundance in the Earth's crust. The data collected from these measurements can provide valuable insights into the geological composition and history of the surveyed area.

4. Results And Discussion

4.1 Ratio maps

4.1.1 Interpreting the eU/eTh Ratio Map

The uranium-to-thorium (eU/eTh) ratio map presented in Figure 3 highlights a consistent trend of uranium enrichment compared to thorium across various regions within the study area. Notably, significant enrichment zones are identified in Enugu, Ozalla, Agbani, Abaw-Ogugu, and Umuowalagu. Enrichment is also evident in the Anambra Basin, particularly in the Atta, Oru, Achina, Aguata, and Orumba areas. On the other hand, uranium levels are dropping compared to thorium in the Basement complex and places like Ezeagu, AforUgwu, Ebenebe, and Udi. This shows that the study area has different geological processes and mineral distributions.

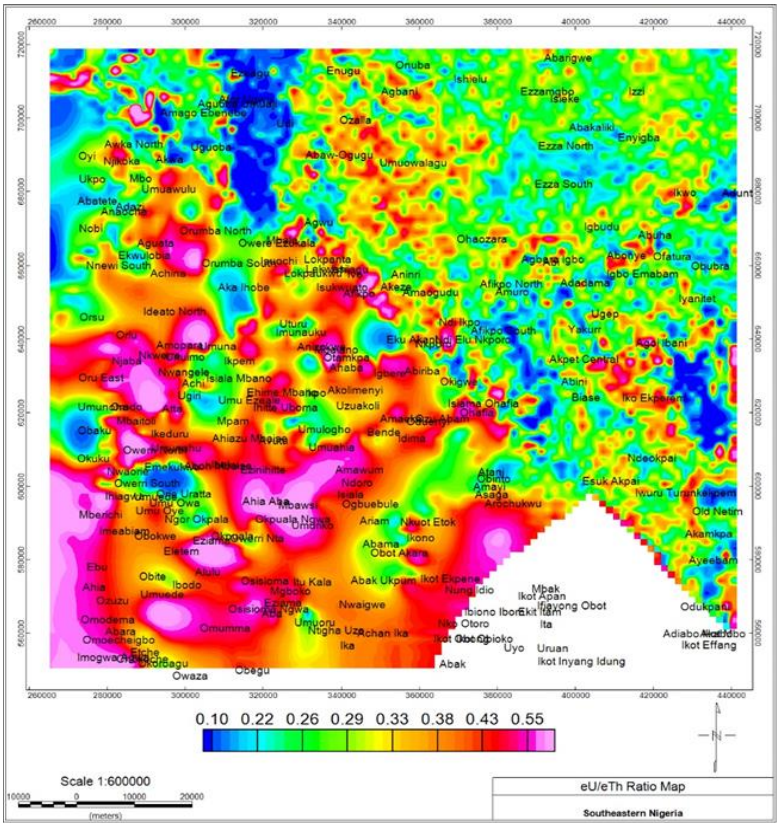

Figure 3: U/Th Ratio Map of the Study Area

4.1.2 Thorium to Potassium (Th/K) ratio map

Figure 4 reveals distinct patterns in the Th/K ratio across the study area. High Th/K ratios are prominently observed in the northwestern sector, indicating localised enrichment of thorium relative to potassium. Conversely, areas such as IsiamaOhafia, Ohafia, Abam, and Atani exhibit notably low concentrations, suggesting a limited thorium and potassium presence. This trend extends to locations like Obinto, Uturu, and Imunauku, indicative of a widespread low Th/K ratio distribution. In Abakaliki, Ezza, and Enyigba, there are areas with moderate enrichment that point to possible hydrothermal activity that changes the amounts of thorium and potassium present. Similar enrichments are noted in the Ezzamgbo, Ohaozara, Lokpaukwu, Lokpanta, and Ishiagu regions, signifying diverse geological processes at play.

In the study area, a corridor with lower anomalous concentration can be traced from Aka Ihobe, passing through Isuochi, and extending to Owere-Ezukala, Awgu, and Abaw-Ogugu. This corridor further extends to Ozalla and Onuba, forming a significant geological feature. In stark contrast, the basement complex of the region consistently exhibits low thorium-to-potassium (Th/K) and uranium-to-potassium (U/K) ratios. These low ratios are indicative of widespread alteration processes that have played a crucial role in shaping the geological dynamics of the region. These new findings shed light on the complicated way that geological factors affect the levels of Th/K and U/K in the study area. They also show how important local geological processes are in figuring out radionuclide concentrations.

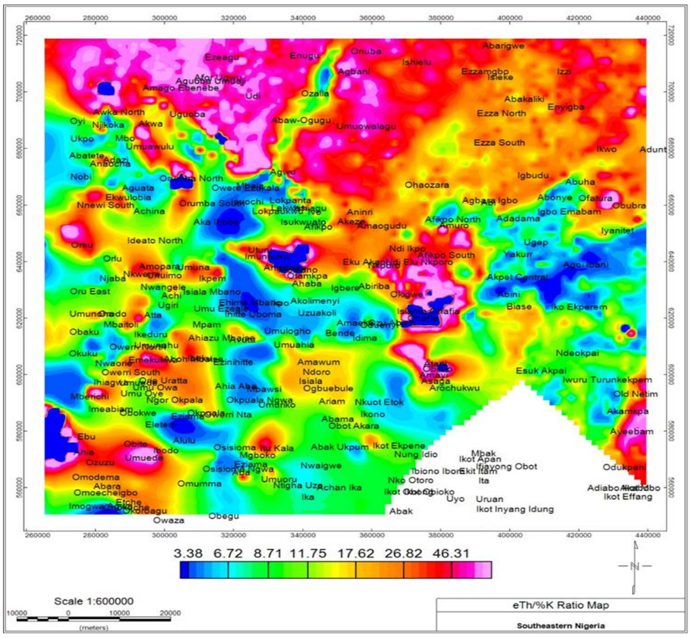

Figure 4: Th/K Ratio Map of the Study Area

4.1.3 Uranium to Potassium (eU/K) ratio map.

The Uranium to Potassium (eU/K) ratio map, as depicted in Figure 5, reveals a distribution pattern that closely mirrors the Th/K distribution across the study area. However, an exception to this pattern is observed in the northwest region, which is characterized by a low lithologic unit. This discrepancy suggests unique geological processes at play in this particular region. The combined presentation of ratio maps in Figures 3, 4, and 5 highlights several distinct trends. Notably, there is a preferential enrichment of thorium over uranium, potassium over thorium, and potassium over uranium across the study area. These trends provide valuable insights into the geological processes and conditions that have shaped the region's landscape over time.

Low eTh/K ratios are robust indicators of potassium alteration. This is clearly exemplified by observations in locations such as IsiamaOhafia, Ohafia, Abam, and Atani, among others. In these areas, the low eTh/K ratios suggest significant potassium alteration has occurred. In contrast, places like Ezeagu, Udi, and AforUgwu exhibit lithologies that have remained relatively unchanged over time. Here, the ratios are normal and align with the expected amounts of potassium and thorium in the crust. This stability in the ratios suggests that these areas have been less affected by alteration processes.

The moderate eTh/K ratio observed in the northeastern part of the study area points to the presence of potassium anomalies. These anomalies warrant further investigation, separate from those that are merely caused by changes in the rock layers. This finding underscores the importance of discerning between geological variations and anomalies that may offer insights into underlying mineralization or structural features deserving further investigation.

Furthermore, the ratio maps effectively delineate lithologic boundaries, particularly in the northwestern section of the study area. This unit reflects high thorium and uranium concentrations within the sandstone units around Enugu, Ozalla, AbawOgugu, and Agwu areas. This contrasts with the low uranium, moderate thorium, and low potassium sandstone units at Ezeagu, Udi, AforUgwu, and Ebenebe.

These findings highlight the diverse geological compositions and processes shaping the distribution of uranium, thorium, and potassium ratios throughout the study area. They underscore the complexity of the region's geological history and the intricate interplay of processes that have contributed to its current state. This comprehensive understanding of the region's geological dynamics is crucial for future research and exploration activities in the area.

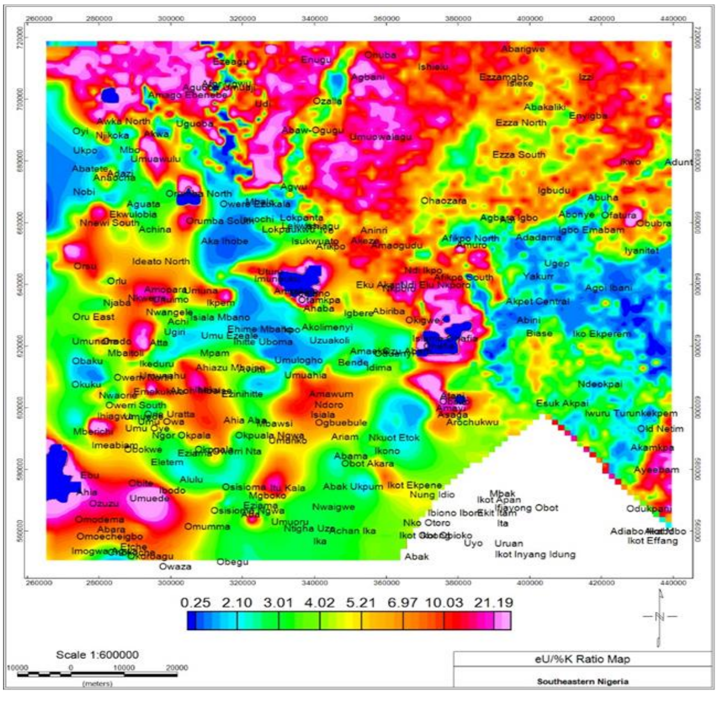

Figure 5: U/K Ratio Map of the Study Area

4.2 Analytical Statistical Insights

The methodology adopted for data analysis in this study involved employing threshold, diagnostic ratio, and average crustal radioelement concentration techniques. These methods facilitated the calculation of mean, minimum, and maximum values, alongside determining the standard deviation and coefficient of correlation for radioelement concentrations. The primary aim was to unveil any statistical correlations among the radiation parameters under scrutiny.

By leveraging the statistical functionalities embedded within "Microsoft Excel 2019 and Geosoft Oasis Montaj v8.4," we conducted a comprehensive analysis of radioelement concentrations. We calculated key statistical measures such as the mean, standard deviation, and correlation coefficients, which are fundamental to understanding the distribution and relationships among the data. The results of this detailed statistical analysis are presented in Table 1. These results provide valuable insights into potential relationships among the examined radiation parameters. By identifying and interpreting the underlying trends and patterns within the dataset, we gain a deeper understanding of the geological dynamics and processes that influence the concentrations of radioelements in the study area. This analysis is crucial for further geological studies and exploration activities in the region.

4.3 Comparative Analysis of Radioelement Concentrations

Table 1 presents the average concentrations of uranium, thorium, and potassium in the study area, recorded as 3.02 ppm, 11.22 ppm, and 0.43% respectively. These values provide a snapshot of the radioelement composition in the region. To put these figures into perspective, the UNSCEAR report provides global average data for these elements in rocks. The report states that the global averages for uranium-238 (^{238}U), thorium-232 (^{232}Th), and potassium-40 (^{40}K) are 33 $Bqkg^{-1}$ (equivalent to 2.973 ppm), 45 $Bqkg^{-1}$ (equivalent to 11.084 ppm), and 420 $Bqkg^{-1}$ (equivalent to 1.342%), respectively (UNSCEAR 2000). This comparison between the local and global averages offers valuable insights into the geological characteristics of the study area and its deviation from global norms.

Comparing these values reveals that the mean concentrations of ^{238}U and ^{232}Th in our study area slightly exceed the global averages, albeit remaining within the anticipated range. This suggests that uranium and thorium concentrations in the study area are generally consistent with global norms. However, the concentration of ^{40}K falls below the global average, indicating a lower potassium concentration compared to the global standard. These findings highlight the variation in radioelement concentrations between the study area and the global average, shedding light on the unique geological characteristics and processes influencing the distribution of uranium, thorium, and potassium within the region.

Table 1: Analysis of Radiometric Data: Statistical Insights

Radionuclide	eU (ppm)	eTh (ppm)	K (%)	Dose (ppm)
Minimum	0.80	1.40	0.40	7.50
Maximum	16.80	65.50	2.60	247.10
Mean	3.02	11.22	0.43	52.38
Standard Deviation	1.49	5.75	0.46	22.85

In sedimentary rocks, Galbraith & Saunders (1983) documented the average content ranges of ^{238}U, ^{232}Th, and ^{40}K as (0.1 to 1.7 ppm), (0.4 to 11.2 ppm), and (0.1 to 2.7%), respectively. Interestingly, our radiometric data reveals that the average content of ^{238}U and ^{232}Th exceeds the ranges reported, indicating potentially elevated concentrations within the study area (Galbraith and Saunders, 1983). However, the concentration of ^{40}K falls within the documented range, suggesting consistency with expected potassium levels.

Gupta emphasizes that the standard deviation reflects the degree of uniformity in a dataset: higher values imply lower uniformity, and vice versa. Notably, the standard deviation of radionuclide concentrations (^{238}U, ^{232}Th, and ^{40}K) in our study area is lower than their mean activity concentrations (Gupta, 2001). This observation indicates a high degree of uniformity in the distribution of these radionuclides across the study area, implying consistent levels throughout the sampled regions.

These statistical insights deepen our understanding of the variations and uniformities in radionuclide concentrations within the study area, shedding light on the geological characteristics and processes influencing their distribution. Such findings are instrumental in elucidating the geochemical dynamics and geological history of the study area.

4.4 Ratios and Geochemical Dynamics of the radioelements

Table 2 presents a detailed overview of the activity ratios (U/Th, U/K, and Th/K) of the radionuclides analyzed in this study. The U/Th ratio, which represents the ratio of uranium to thorium, spans a range from 0.10 to 0.55, with an average value of 0.333. This is particularly noteworthy when compared to the average U/Th ratio of the upper crust, which highlight as being 0.8 (Powell et al., 2007). This comparison suggests that the concentrations of uranium and thorium in the study area are lower than the typical concentrations found in the upper crust.

The Th/U ratio is another important metric in our analysis. As explained by the Th/U ratio serves as an indicator of the relative depletion or enrichment of these radioisotopes (Orgun et al., 2007). El-Bahi further elucidates this point by stating that a Th/U ratio higher than one signifies that thorium is less mobile in the earth's chemical environment compared to uranium (El-Bahi, 2004). As a result, sediments tend to accumulate more ^{232}Th than ^{238}U. In our study area, the average Th/U ratio is 28.30. This high ratio indicates that sediments within the Southern Benue Trough are more likely to accumulate ^{232}Th than ^{238}U. This finding provides valuable insights into the geological processes at play in the region and the factors influencing the distribution of these radionuclides.

These activity ratios provide valuable insights into the geochemical processes and sedimentary dynamics shaping the distribution and accumulation of uranium and thorium isotopes within the study area, contributing to our understanding of its geological characteristics and history. These findings underscore the intricate geochemical dynamics at play within the study area, revealing insights into the relative abundance and distribution of uranium and thorium isotopes. The calculated activity ratios offer valuable information regarding the geological processes and depositional environments influencing the concentration patterns of these radionuclides. By comparing the observed ratios with established values and trends in the literature, this study contributes to our understanding of the geochemical characteristics and sedimentary processes within the Southern Benue Trough region.

Table 2: Radionuclide Activity Ratios in the Study Area

Ratio	U/Th	Th/K	U/K
Minimum	0.100	3.380	0.250
Maximum	0.550	53.210	23.190
Mean	0.330	28.300	11.720

4.5 Correlation of abundance of radioelements within the study area.

In Figure 4a, a notable R^2 value of 0.730 establishes a strong relationship between uranium and thorium concentrations, indicating their interdependence within the study area. Figures 4b and 4c, on the other hand, show that R^2 values for uranium and thorium (0.006) and potassium and thorium (0.004) are below 0.5, which means that the two groups don't have a strong relationship with each other and their concentrations don't depend on each other.

Table 2 presents the average values for the U/Th, Th/K, and U/K ratios, which stand at 0.33, 28.30, and 11.72, respectively. These ratios help us understand geochemical processes and mineral distributions in the study area by showing how common different radioelements are and how they relate to each other. The statistical analysis provides valuable information for interpreting the complex dynamics governing radioelement concentrations and their interactions in the geological environment.

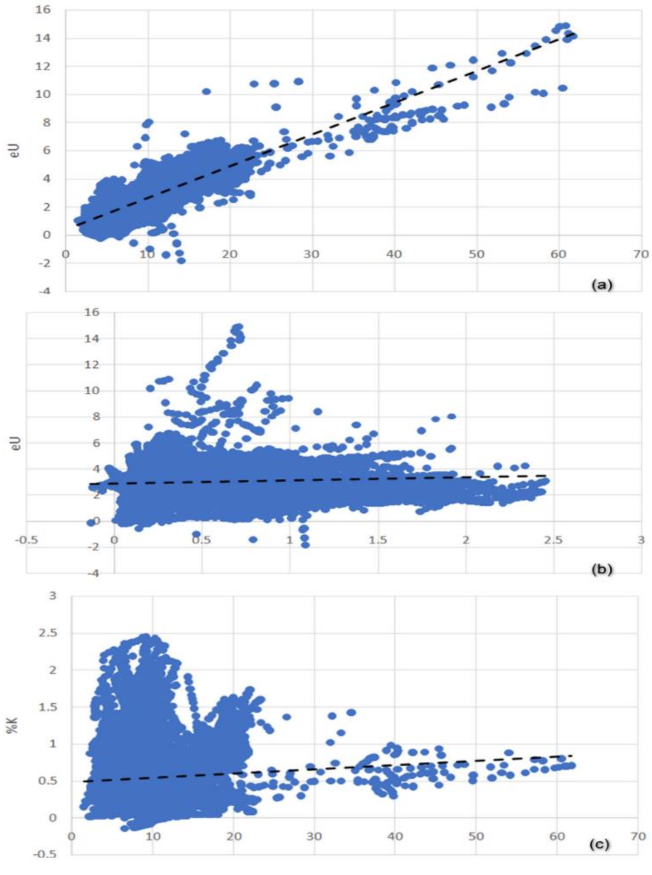

Figure 4: Correlation of abundance of radioelements within the study area.

5. Conclusion

Statistical analysis using correlation method was performed on radiometric data in other to reveal patterns and associations between different radioelements. The analysis of radiometric data indicates that the mean concentrations of U, Th, and K stand at 3.02 ppm, 11.22 ppm, and 0.43%, respectively. These values fall within the world average range for these elements. The correlation of abundance of radioelements revealed an R2 value of 0.730 between Uranium and Thorium. The value obtained is above 0.5 and shows a good relationship between the two. This in turn indicates that their concentrations are dependent on each other. But R2 values obtained in correlation between Uranium and Potassium is 0.006, and Potassium and Thorium is 0.004, both are less than 0.5. This depicts a weak relationship between the concentrations of the radioelements and in turn revealed that the concentrations of the radioelements are independent of each other. These findings will aid in mineral exploration, environmental monitoring, geological and geophysical studies, it will also enable predictions about the presence and concentration of specific radioelements in certain geological formations

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