

Empirical Relation Between Magnetic and Radiometric Survey in Bitumen Area, Ogun State, Nigeria

Empirična povezava med magnetnimi in radiometričnimi raziskavami na območju bitumna, zvezna država Ogun, Nigerija

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Abstract

One of the vital roles played by both magnetic and radiometric surveys is identification and delineation of mineral deposits. The study area, Imeri, which lies between latitude 6 °45'N to 6 °48'N and longitude 3 °58'E to 3 °59'E, has been established for bitumen deposition. The responses of mineral deposition to different geophysical methods differ from place to place due to variation in climate and bedrock composition. In this study, two geophysical techniques—magnetic and radiometric methods—were adopted to investigate the magnetic anomalous and radiometric flux responses around the bitumen deposit area. The study also intends to establish a model-like relation between the radiometric parameters and the magnetic anomaly observed. Statistical inferences for the established relations were deduced using the t-test at 0.05 significance levels. The result obtained showed that uranium and thorium concentration responses along the two traverses were in good agreement with that of magnetic intensity. The claim was accounted for based on the correlation result, which ranged between 74%–79% and 84%–89% for uranium and thorium, respectively, with magnetic intensity along the two traverses. In order to validate the claim, the t-test was used. The result obtained showed that there exists no significant difference between the two geophysical methods; the result for the t-test has critical value > calculated value (p -values > 0.05). Based on this, the empirical relations were deduced for magnetic anomalous response and radiometric parameters. This work has therefore proven the two techniques to be versatile for bitumen prospecting in the study area.

Keywords: bitumen, magnetic, uranium, survey, t-test

Povzetek

Glavna vloga tako magnetnih kot radiometričnih raziskav je identifikacija in oris mej rudnega telesa. Področje Imeri, ki leži med 6 °45' in 6 °48' severne zemljepisne širine ter med 3 °58' in 3 °59' vzhodne zemljepisne dolžine, vsebuje nahajališče bitumna, ki se ujema z obogatitvami železa. Odzivnost rudnega telesa na različne geofizikalne metode variira z geografsko lego glede na razlike v podnebju in sestavi kamninske podlage. Pričujoča študija predstavlja uporabo magnetnih in radiometričnih geofizikalnih metod za določanje magnetnih anomalij in radiometričnega toka v okolici bitumenskega telesa. Namen raziskave je tudi vzpostavitev empiričnega odnosa med radiometričnimi parametri in opazovano magnetno anomalijo. Statistična povezava med obema lastnostma je bila določena s pomočjo t-testa pri statistični značilnosti 0,05. Dobljeni rezultati kažejo, da sta koncentraciji urana in torija sorazmerni magnetni intenziteti. Korelacija je med 74–79% za uran ter 84–89% za torij. Korelacija je bila potrjena s t-testom. Dobljeni rezultati ne potrjujejo značilne razlike med rezultati obeh geofizikalnih metod, saj kritična vrednost presega izračunano vrednost (p -vrednost > 0.05). Glede na to je bila določena empirična povezava med anomalnim magnetnim odzivom in radiometričnimi parametri. Delo dokazuje raznolikost obeh tehnik pri iskanju bitumna na obravnavanem območju.

Ključne besede: Bitumen, magnetni, uran, raziskava, t-test

Introduction

The magnetic and radiometric surveys can be done either on the ground or by air [1]. They have been found to be mostly carried out together, without one affecting the other. This can be observed in the aerial survey, where the magnetometer and gamma ray spectrometer were flown together on the same aircraft. These two methods can be integrated, as they have a tendency to delineate the surface and subsurface structural features, and the nature of distribution of the radioelement can be inferred from magnetic interpretation [2–5]. The results obtained from the two surveys always give an account of similar features in their interpretation. The magnetic and radiometric methods are used to gather soil body-related information [6–8].

Radiometric measurements allow the detection and mapping of naturally occurring radioactive emissions (γ ray) from rocks and soils. Gamma radiation occurs as a result of the natural disintegration of elements such as U, Th, and K [9]. Bolaji [10] reported that the level of environmental radionuclide confinement depends on the geology and geography of a given area; and that the geochemistry of each element also played a significant role in its migration from the soil. Mining, mineral processing, and industrial activities have long been linked to increased levels of radionuclides in soil in their vicinity [11].

In the recognition of anomalous response variation in the radioactivity level, radiometric survey is of great importance. The use of this method for geological mapping helps to indicate the presence of radioactive occurrence and deposits [12]. The use of the radiometric method has been found in characterisation of cretaceous geology [13], dyke and manganese exploration [14], hydrothermal gold mineralisation [15–17], lithological mapping and environmental monitoring [18, 19], and many others.

Magnetic survey defines the local variations in strength and direction in the earth's magnetic field, which can accurately locate the position of shear zones and faults [20]. It helps to locate mineral deposits by identifying specific rock types and geological features [21]. The variation of magnetic mineral composition due to the differences in the stratified bedrock layers makes

this method suitable for hydrothermal mineralisation and mapping rock lithology [22].

Magnetic survey is an important geophysical technique that is especially suitable for identifying surface archaeological remains and magnetic contact [23–26], identification of faults [27–29], edge source detection [30–32], mineral prospecting [33, 34] and many others.

A number of authors [1, 17, 35–45] have made use of the combination of magnetic and radiometric methods in their work, and the results obtained are in good agreement with each other.

In the work of Ogunsanwo et al. [46], ground and airborne radiometric surveys were compared and empirical models were established among their radiometric parameters. Similar to the aforementioned works is that done by Ammar et al. [47], Fouad [48], and Youssef [49], where ground and airborne radiometric data sets were correlated and empirical models were obtained for different bedrock compositions.

In this study, we investigate the possible relationship between the magnetic and radiometric surveys carried out around the bitumen deposit area by (1) comparing the radiometric and magnetic anomalous responses due to the bedrock composition of the study area, (2) deducing an empirical relation between the two geophysical surveys, and (3) validating the generated models using inferential statistical tests for standardisation.

Geological description of the study area

Imeri, the study area, is well recognised as a bitumen-rich area in the eastern part of Ogun state. It was found on geographical coordinates between the latitude 6 °45'N to 6 °48'N and longitude 3 °58'E to 3 °59'E along the Benin-Sagamu expressway, in the tropical rainforest region, Southwestern Nigeria. The study area is bounded by Idono in the north, Igbaga in the east and Imagbon in the south, and lies on the Abeokuta formation (Figure 1). The lithostratigraphical classification of the study area reported that the rock is basically made up of ferruginous sandstone, limestone, and shale [46]. The bitumen, from geochemical perspective, was detected to be rich in mineral-bearing elements such as iron, nickel, and lead [50].

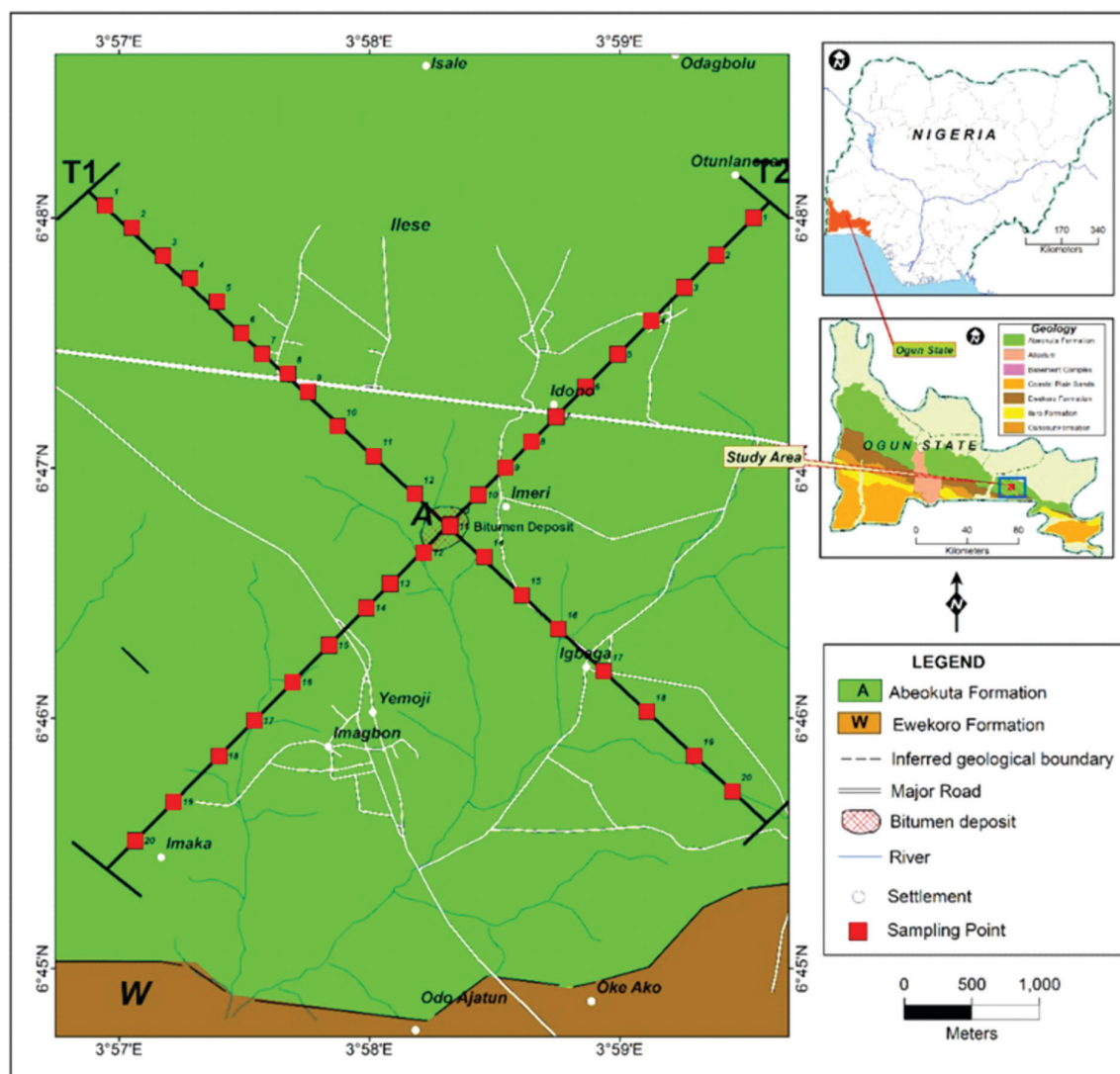


Figure 1: Geological map indicating the two traverses and the sampling points.

Materials and methods

Ground magnetic survey

This study makes use of a proton magnetometer to carry out the magnetic survey over the bitumen deposit area. Two traverses (T1 and T2) were surveyed, each 0–100 m long, with spacing distance of 5 m. The total magnetic field intensity was obtained across the two traverses and necessary corrections, such as diurnal reduction and many others, were employed. The essence of this is to filter out the regional anomaly from the total magnetic intensity, so one is left with the residual magnetic anomaly.

Ground radiometric survey

With the aid of a global positioning satellite (GPS) along the magnetic traverses, soil samples were collected. A total number of 40 soil samples were taken and prepared for radiometric analysis. The prepared samples were then taken to the radiometric laboratory of Federal University of Agriculture, Abeokuta, for gamma ray spectrometric analysis.

Radiometric measurement and conversion

The radiometric measurement was carried out using a gamma ray spectrometer with 2" by 2" sodium iodide, NaI(Tl) detector coupled to the

digibase multichannel analyser. The system calibration was performed using International Atomic Energy Agency [51] reference materials: RGK-1, RGU-1, and RGTh-1 for K, U, and Th activity measurements, respectively. The procedure for calibration and measurements were adopted from Grasty et al. [52].

The laboratory radioelement concentrations were obtained in Becquerels per kilogram (Bqkg⁻¹). The concentration in Bqkg⁻¹ was then converted to ppm and % using a conversion factor given by the Polish Central Laboratory for Radiological Protection [53], as shown in equations (1–3) for uranium in ppm, thorium in ppm, and potassium in %, respectively.

$$C_U(\text{ppm}) = C_U(\text{Bqkg}^{-1}) \times 0.08045 \quad (1)$$

$$C_{Th}(\text{ppm}) = C_{Th}(\text{Bqkg}^{-1}) \times 0.24331 \quad (2)$$

$$C_K(\%) = C_K(\text{Bqkg}^{-1}) \times 0.003296 \quad (3)$$

where C_U , C_{Th} , and C_K are the concentrations of ²³⁸U, ²³²Th, and ⁴⁰K, respectively.

Empirical models

In this study, three empirical relations (models) are to be deduced as presented in equations (4–6). The models show the possible relationship existing between the magnetic anomalous response and the three radiometric parameters: uranium, thorium, and potassium, respectively.

$$M = pU_r + q \quad (4)$$

$$M = pTh_r + q \quad (5)$$

$$M = pK_r + q \quad (6)$$

M is the measured magnetic anomalous data set.

U_r is the measured anomalous uranium survey data.

Th_r is the measured anomalous thorium survey data.

K_r is the measured anomalous potassium survey data.

p and q are correctional constants to be determined.

Statistical inference test

In order to validate the models generated, a statistical inference test must be carried out on the measured survey data for the two geophysical methods used. In this regard, the t-test was found suitable and appropriate.

T-test

This test was carried out for the testing hypothesis concerning the mean difference of pairs of the data set, provided the variance of the two samples are equal [19].

The t-test was given by Dixon and Massey [54] as presented in equation (7):

$$t_{n_1+n_2-2} = \frac{x_1 - x_2}{S_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2} \right)} \quad (7)$$

where

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}$$

x_1 and x_2 are the mean of the two samples;

S_p^2 is the pooled variance;

S_1^2 and S_2^2 are the variance of the two samples;

$n_1 + n_2 - 2$ is the degree of freedom;

n_1 and n_2 are the size of the two samples.

Two hypotheses are as follows:

H0: There is significant relationship between the anomalous values obtained for the two geological surveys. (Heterogeneous)

H1: There is no significant relationship between the anomalous values obtained for the two geological surveys. (Homogenous)

When t calculated $> t$ critical, the H1 hypothesis is rejected, while H0 is adopted.

If t calculated $< t$ critical, then H1 hypothesis will be accepted.

Results and discussions

The result obtained for magnetic anomaly and the three radioelements (uranium, thorium,

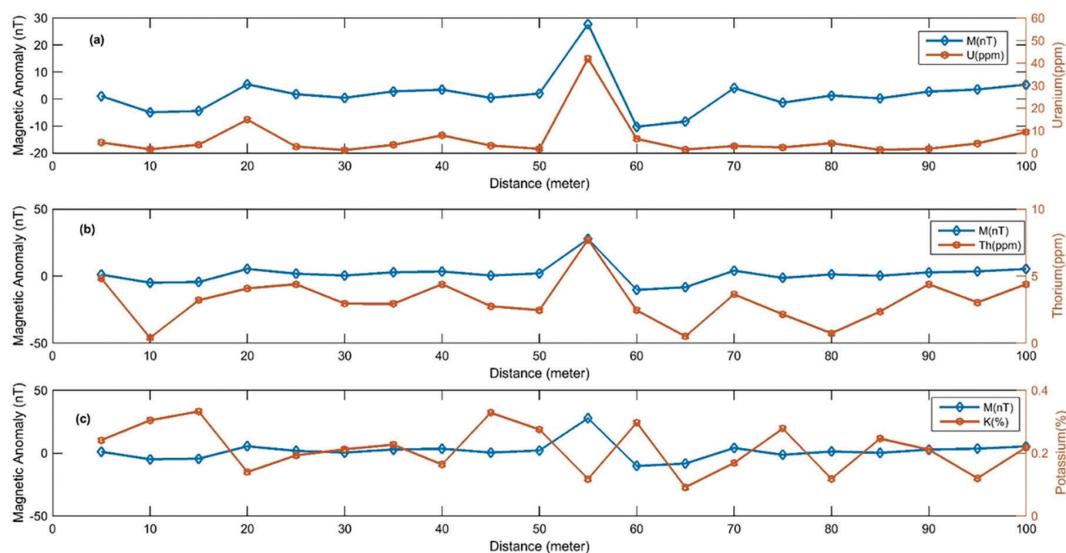


Figure 2: Variation between the magnetic intensity and that of (a) Uranium concentration, (b) Thorium concentration, (c) Potassium concentration at T1.

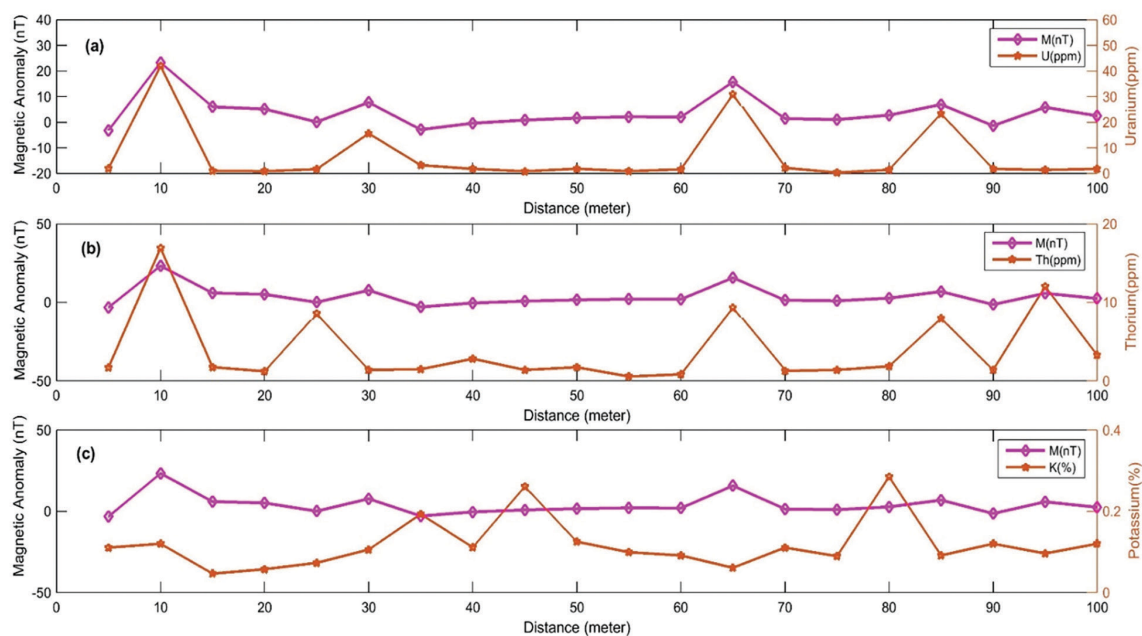


Figure 3: Variation between the magnetic intensity and that of (a) Uranium concentration, (b) Thorium concentration, (c) Potassium concentration at T2.

and potassium) are presented in Figures 2a-c and Figures 3a-c for T1 and T2 respectively. The result obtained revealed the magnetic profile to range from -10.19–27.76 nT, while uranium is between the range of 1.43–42.09 ppm. Thorium and potassium were in the range of 0.40–7.73 ppm and 0.09–0.33%, respectively, along T1. Figure 2a shows a comparison between the magnetic and uranium profiles.

The two profiles show similar features. The spot of peak magnetic intensity observed coincides with that of uranium concentration.

The peak point of the profile in Figure 2a indicates the epicentre of the bitumen deposit. This implies that at the epicentre of the deposition, high anomalous response was accounted for, at the same point where both magnetic intensity and uranium concentration profile

coincide. Figure 2b also accounted for high anomalous response of thorium concentration and magnetic intensity at the same spot (epi-centre) similar to that indicated in Figure 2a. Unlike uranium, thorium concentration does not conform totally to the trend of magnetic intensity; there exists some disparity toward the end of the traverse. Olowofela et al. [18] mentioned that sandstone and other features such as the underlying rock units of an area may give results of elevation of uranium and thorium concentration.

Potassium concentration and magnetic intensity are observed to have inverse relation almost at every point along the traverse. Figure 2c supported the above claim, most especially at the point where the magnetic intensity accounted for the peak response and the potassium concentration was found to have low value. There exist, however, a variety of spots with high potassium response which are different from that shown in the uranium and thorium signature in Figures 2a, b.

In T2, the magnetic profile ranges between -3.18–23.30 nT, while uranium was found in the range of 0.32–41.90 ppm. Thorium and potassium were obtained in the range of 0.55–16.94 ppm and 0.04–0.28%, respectively. Along traverse two, uranium concentration profiles were found to coincide with the magnetic intensity profile at three different points of high anomalous response. This may be attributed to the fact that the bitumen deposition may be present in those areas.

Ahmad et al. [55], Wassila and Ahmed [56], Mlwilo et al. [57], and Makweba and Holm [58] pointed out in their work that the mining, mineral processing, and industrial activities have long been linked to increased levels of radioanuclides in the soil. The region with peak anomalous magnetic responses may also be a result of presence of ferromagnetic substance in the bitumen. This implies that the bitumen is rich in ferromagnetic material around that area. The ferruginous contents elevate the uranium and thorium concentrations of any area while feldspar contents contribute to potassium elevation.

The results obtained identify some areas of interest, such that the spot at which the ferruginous content of the rock is high, the feldspar

content is low, and vice versa. Since the magnetic anomalous responses observed are in line with uranium and thorium concentration responses, and feldspar contains potassium, which is radioactive, it was assumed that areas of high potassium concentrations will be areas of low magnetism and vice versa. Hence, the radiometric survey would serve as a check on the magnetic anomaly interpretation, thereby reducing the ambiguity inherent in potential field data analysis. Generally, from field observations there exists an inverse relationship between the ferruginous and the feldspar contents of the sandstone. This implies that the areas of inverse relationship are more pronounced between the magnetic and potassium anomalous response: that is, high magnetic anomalies coincide with spots of low potassium concentration responses (Figures 3a; 4a, d). This means the more iron content in the sandstone, the less the feldspar content, and vice versa.

Result for magnetic anomalies and radioelement distributions

In order to visualise the pattern of magnetic anomalies and radiometric responses in the bitumen deposit, the 2D and 3D pictorial representations were adopted. Figures 4 and 5 showed the 2D distribution of magnetic anomalies, and the three radioelement concentrations in T1 and T2 respectively. In similar context are the 3D representation of the magnetic anomaly and the three radioelement concentrations in Figures 6 and 7 for the two traverses.

In our study, the anomalous responses due to both the magnetic intensity and the radioelement concentrations were classified into three distinct levels: low, moderate, and high. The region with pink colour signifies the area of intense or high response of both magnetic and radioelements, while the yellowish-green represents the moderate response to the bitumen deposition. The blue colours denote the low responses in both the magnetic and radioelements.

The magnetic anomaly (Figure 4a) behaves in a similar way to uranium concentration (Figure 4b) response. Thorium concentration responses (Figure 4c) were also found to be closer to the magnetic anomalous response but not as much as that of uranium response.

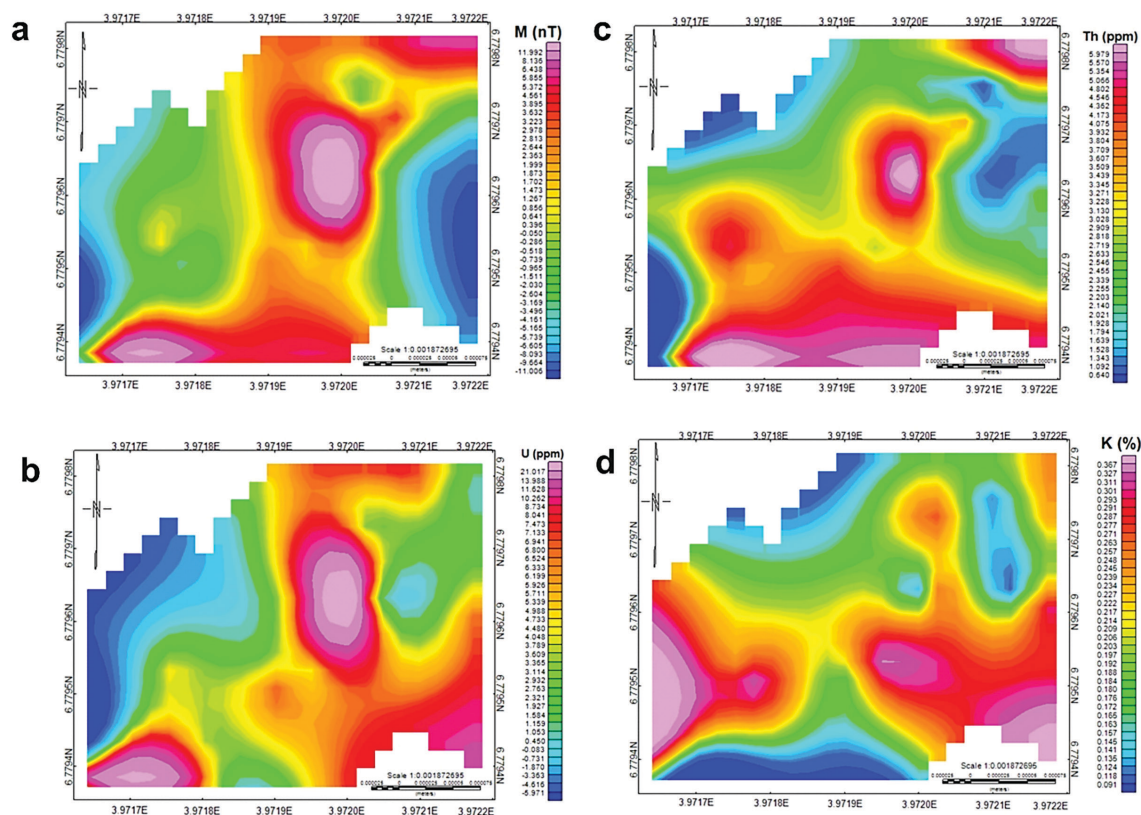


Figure 4: Contour map showing the distribution of (a) magnetic intensity, (b) uranium concentration, (c) thorium concentration, (d) potassium concentration in T1.

In Figure 4a, low and moderate magnetic anomalous levels were observed at the eastern and western part while the high level of magnetic response was found associated with the central part, trending southward along the traverse. Figure (4b) accounted for low and moderate uranium concentrations in the western part trending south, while high uranium concentration was found in the SW corner and the central part, trending east along traverse 1.

In the central part of Figure 4 (a, b, and c) exists a distinct circular shape with intense response due to magnetic, uranium, and thorium to bitumen deposition. The circular portion with intense response was found to be the exact location of the bitumen deposit. The SS part of the magnetic anomaly corresponds with that of thorium concentration, having high responses and inversely varying with potassium, having low response in the identified area. In Figure 4d, a distinct very high potassium concentration was observed in eastern and

western sections, while moderate followed by low concentrations were accounted for in the SS section of traverse 1. At the upper part of the high level lies the moderate level of potassium concentration.

The magnetic anomalous response (Figure 5a) to the bitumen deposition in traverse 2 was not as high as in traverse 1. Moderate and low magnetic responses dominate the area with some spots of intense responses. The high uranium concentrations are found in line with those spots identified in the magnetic intensity. The high level of uranium concentrations is found to be more dispersed, compared to that of magnetic intensity (Figure 5b). Four zones of low thorium concentration level were identified along the traverse, while high levels of thorium concentrations were found in the SE and SW, trending SS along traverse 2 (Figure 5c). Similar anomalous features were observed in the SW corner of Figures 5a–c) for magnetic, uranium, and thorium responses, respectively.

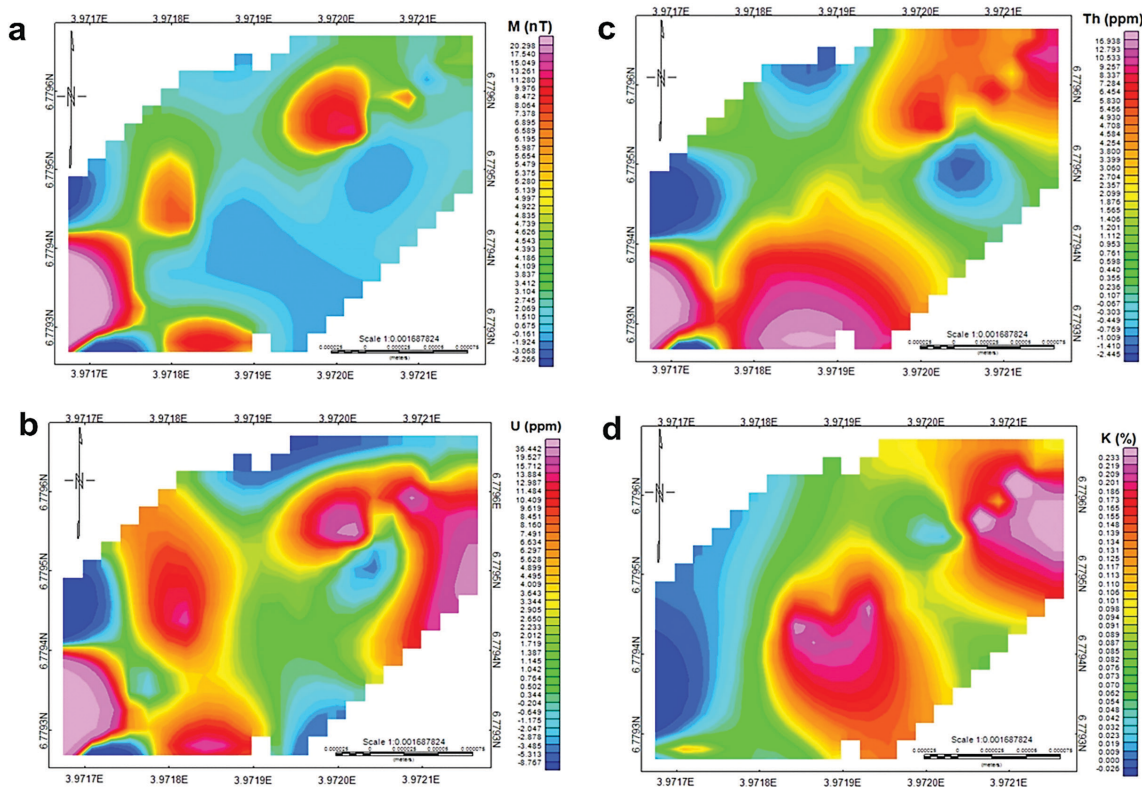


Figure 5: Contour map showing the distribution of (a) magnetic intensity, (b) uranium concentration, (c) thorium concentration, (d) potassium concentration in T2.

Three distinct levels were experienced in traverse 2 for potassium distribution (Figure 5d). Low potassium concentration was observed at the extreme western section, while high concentrations were found associated with the central and NE part. The moderate concentration was observed at the central part of this section encompassing the high concentration region. Both traverses 1 and 2 accounted for high potassium concentration, which may be due to the presence of sandstone, the predominant bedrock composition of the area.

The clearer views of the magnetic and radiometric anomalous responses are shown in Figures 6 and 7. The region with a sharp peak indicates the zone of high levels of anomaly for both magnetic and radiometric surveys. The steep region is also an indicator of anomalous response, but with low magnetic or radiometric intensity, while the flat area implies uniformly distributed magnetic and radiometric intensity. The magnetic map gives an account of magnetic anomalies due to local variations of the magnetic field produced by magnetic material

in the subsurface layers. The 3D surface plot (Figures 6 and 7) provides a better presentation of the anomalous responses accounted for by magnetic and radiometric survey over the bitumen deposition when compared to that of the 2D contour plot. The potassium surface plot accounted for more anomalous points compared to that of uranium and thorium. The region where the magnetic anomaly was situated was similar to that of uranium anomalous response around the NE section of traverse 1, (Figures 6a and b). The anomalous point was not only situated in the NE region of traverse 1 for thorium but also visible in the SW region of the traverse.

The 3D surface plot presented for magnetic and uranium responses (Figures 7a, b) also show a similar distinct feature of anomalous peak and steep regions along traverse 2, different from that accounted for in traverse 1. At the central part of traverse 2, a very steep anomalous point was accounted for by magnetism and uranium, while for potassium two sharp high anomalous points were observed.

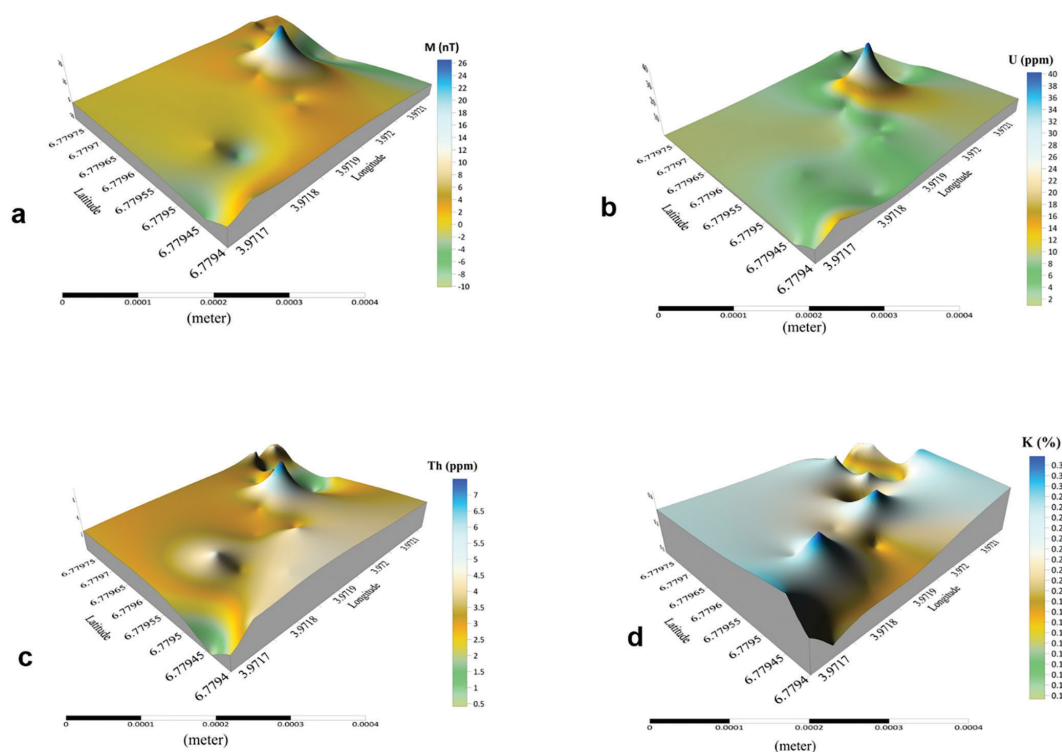


Figure 6: 3D Surface plot of (a) magnetic anomaly, (b) uranium concentration, (c) thorium concentration, (d) potassium concentration in T1.

Generally, potassium is one of the most abundant radioelements in the earth's crust. In view of this, the points of anomalous response are more associated with potassium distribution, as presented in the 3D surface plot. Conversely, the regions with high peaks found in the potassium response are found to be the region with steep or uniform anomalous magnetic and uranium responses. This implies that the potassium anomalous responses vary inversely to that of magnetism and the uranium. The results obtained by both the contour and surface plots showed that the magnetic anomaly associated with the bituminous area has a very strong direct relationship with the uranium and thorium anomalous responses, while potassium has inverse relation.

Linear regression models

In order to establish a significant relationship between the magnetic and the radiometric survey, there is need for a linear and simple mathematical model. The model was obtained with the aid of a regression approach. The magnetic

survey data set and the radioelements (U, Th, and K) were subjected to regression analysis, and a linear relation was established (Figure 8). The result obtained for the two traverses were merged for both the magnetic and radiometric evidence, such that a generalised model for the area can be deduced. Figure 6 shows a positive linear slope for uranium and thorium with magnetic anomaly while negative gradient was obtained for potassium responses to the magnetic anomaly.

Figures 8a, b fall in line with the claim that the bituminous soils on which the survey was carried out are ferruginous in nature, which is rich in both uranium and thorium. Being a ferruginous area, it consists of minerals such as iron (Fe), which has a strong radiometric response to magnetic intensity, with a correlation coefficient (r-value) of 0.84 and 0.67 for uranium and thorium, respectively. On this account, a good agreement is therefore expected between the magnetic and uranium models, likewise that of magnetic and thorium. According to Bassey and Ishaku [39], potassium was reported to respond

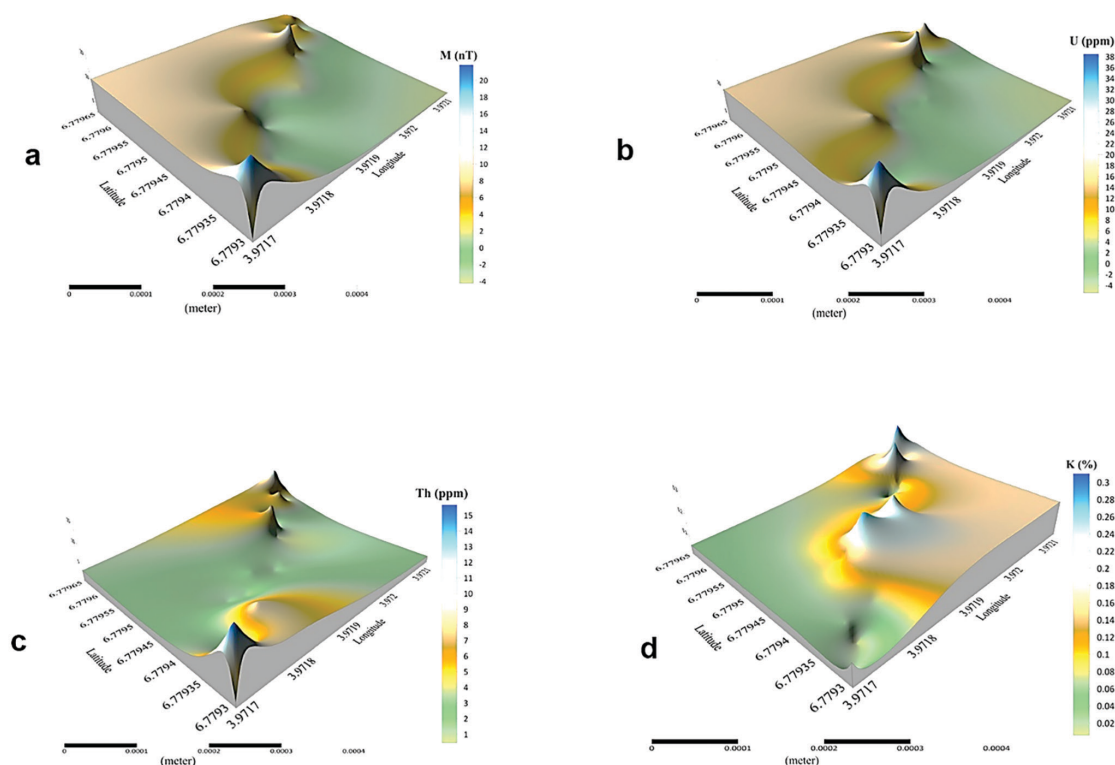


Figure 7: 3D surface plot of (a) magnetic anomaly, (b) uranium concentration, (c) thorium concentration, (d) potassium concentration in T2.

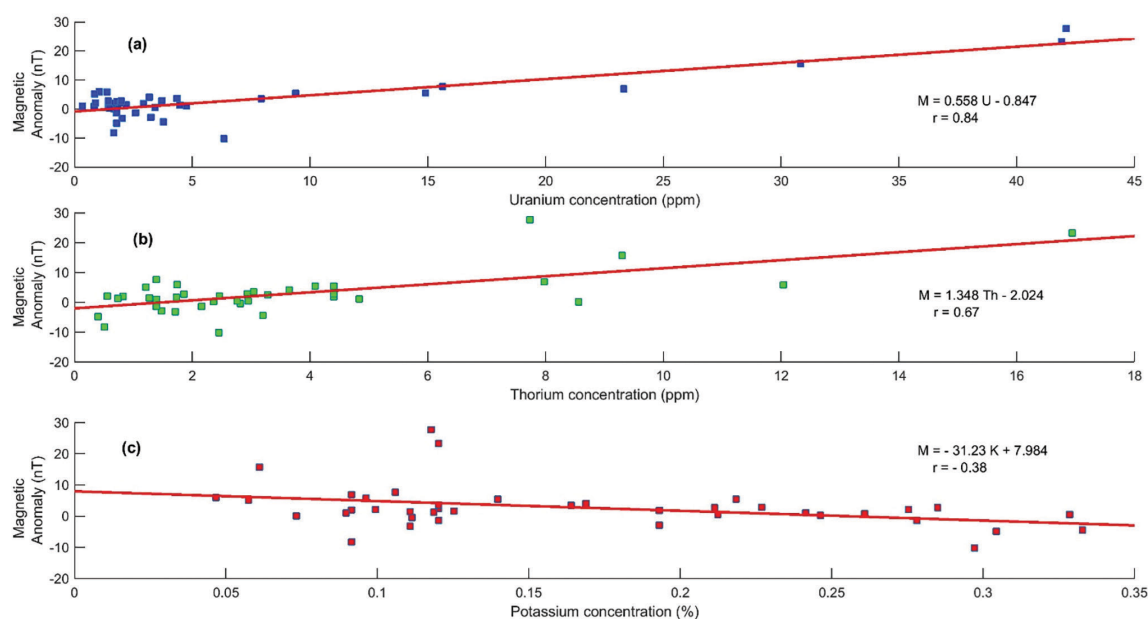


Figure 8: Regression plot between magnetic anomalous response to (a) uranium concentration, (b) thorium concentration, (c) potassium concentration.

well in a feldspar area, unlike that of ferruginous magnetic material. This was revealed in Figure 8c, where an inverse relationship was obtained between

magnetic and potassium response to bedrock composition of the bituminous area, with a correlation coefficient of -0.38.

Table 1: Summary of *t*-test inferential statistics.

	Survey parameters	t-calculated	t-critical	p-value	r-value
Traverse 1	M – U	1.71	2.02	0.09	0.84
	M – Th	0.87	2.02	0.39	0.79
	M – K	–0.89	2.02	0.37	–0.47
Traverse 2	M – U	0.99	2.02	0.32	0.89
	M – Th	0.04	2.02	0.96	0.74
	M – K	–2.66	2.02	0.06	–0.24

The regression model obtained for magnetic to uranium response is as presented in Equation (8):

$$M = 0.558 U - 0.847 \quad (8)$$

The regression model obtained for magnetic to thorium response is as presented in Equation (9):

$$M = 1.348 Th - 2.024 \quad (9)$$

The regression model obtained for magnetic to potassium response is as presented in Equation (10):

$$M = -31.230 K + 7.984 \quad (10)$$

Inferential statistical result

Inferential statistics are basically used to validate the result obtained between two or more variables. In this study, a *t*-test was used to validate the response of magnetic flux and that of radiometric flux over the study area. This is necessary in order to validate the established relations between the magnetic intensity and the radioelements. The result obtained for the three radioelements and magnetic intensity for the two traverses shows that there is no significant difference between them. The critical value is greater than the calculated value (Table 1). This is also in agreement with the result obtained for the *p*-values. The *p*-values results are greater than 0.05, which implies that the hypothesis H1 was adopted while the hypothesis H0 was hereby rejected.

The *t*-calculated tests indicate negative value at traverse 1 and 2, which is in accordance with the *r*-value, with a low negative correlation

coefficient. The result obtained opines that the model generated by uranium and thorium with magnetic intensity due to the two traverses are reliable. The inference result was concluded, as the correlation result depicts a very strong relation of uranium and thorium with magnetic intensity along the two traverses. The models are found to vary from place to place depending on geological bedrock composition. The model generated in this study fit better for uranium and thorium compared to potassium.

Conclusion

In this study, two geophysical surveys, radiometric and magnetic, were carried out in the bitumen deposit area. The study area being a ferruginous zone revealed that the uranium and thorium response results corroborate with the magnetic anomaly deduced, while inverse relationships were obtained between the magnetic and potassium response. Regression analysis was employed to model the magnetic survey data with the three primordial radioelements for standardisation. The models accounted for high correlation coefficients for uranium and thorium with the magnetic anomaly. The two passive geophysical methods used have therefore shown to be linearly related, and useful in identification of anomalous response in the bituminous area.

Declaration Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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