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Delineating Potential Hydrocarbon Targets Through Aero-Radiometric Techniques

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Abstract

The discovery of more hydrocarbon wells remains a major recipe to boost the economy of Nigeria, a major oil producer in Africa. The seismic method is prominent for identifying traps in the oil explorations, but cannot indicate if the trap host hydrocarbon. This gap is usually filled by the radiometric method, its characteristics around the Kolmani well 1 have hitherto not been reported. This research focused on identifying promising locations for hydrocarbon accumulation around the Kolmani Well 1 while using the well as a control. To achieve the objectives of this research, the nature of the radioelements was observed over the Kolmani well1 and the outcome of normalizing potential and uranium was also identified. The average values of potassium (K), thorium (Th), and uranium (U) are 0.277%, 8.917 ppm, and 1.431 ppm respectively. The concentration of the three radioelements, K, Th, and U, decreases over the oil well. This was ascribed to enhanced leaching of natural radioelements caused by hydrocarbon-generated groundwater acids. The result of the normalization of K with Th yields a low concentration of K over the Kolmani well1 and the normalization of U with Th yields a high concentration of U over the Kolmani well1. These were in tandem with the report on the application of the method in previous locations. Hence, the results of the normalization of K and U were used to identify four locations with potential for hydrocarbon exploration. The viability of these locations was confirmed with the positive DRAD (Delineation of Radiometric anomalies) value (ranging from -5.1 to +5.2), a pointer to hydrocarbon accumulation in an area, recorded in these locations and the location of the Kolmani well 1.

Keywords: Kolmani well 1; Normalization; DRAD.

I. INTRODUCTION

Energy consumption outside of the Organization for Economic Co-operation and Development (OECD) has increased dramatically since the start of the twenty-first century, whereas within the OECD, it peaked in 2004 [3][6]. This pattern emphasises the ongoing search for new oil discoveries, particularly in countries like Nigeria where crude oil exports generate around 90% of foreign exchange earnings and 6.33% of GDP [4]. Exploration is still necessary because it is uncertain whether gas, oil, or neither will be found. The process of exploring and producing oil and gas in sedimentary basins involves identifying prospective fields, developing them to produce gas or oil, and ultimately recovering the area after production is finished [1][2]. Urbanisation is accelerated when workers migrate from low-productivity, low-paying informal agricultural labour to formal, higher-paying jobs in the services sector—often the result of oil finds. The highly compensated oil workforce is mostly to blame for this shift in the demand for non-tradable services [5].

Understanding the subsurface is crucial for oil and gas production and discoveries, and geoscience plays a significant part in this [7][8][9]. The purpose of exploration is to get deeper insight into the processes of gas and oil formation, movement, and trapping in subterranean reservoirs [10][11]. Making informed exploration decisions requires the use of cutting-edge technology and geophysical techniques that provide high-resolution subsurface images [12][14][13]. Seismic data collection is essential to this process, and additional information can be obtained through other methods such as electromagnetic surveys. While seismic data can be a valuable tool for visualizing reservoirs and trap structures [16][15][17][18][19], they cannot provide information on the presence of hydrocarbons in a specific trap. Combining seismic and other geological, geochemical, and geophysical data with radiometric survey data can significantly boost the success probability of onshore exploratory wells [36].

With varying degrees of success, hydrocarbon exploration has employed ground, well-logging, and aerial gamma-ray observations since the 1950s [48]. Recent advancements in sensor technology, digital data acquisition, GPS positioning, computer processing, and a better understanding of the physical and chemical processes surrounding hydrocarbon deposits have made airborne gamma-ray surveys much more efficient and cost-effective. To ascertain whether or not oil and gas are present in the subsurface, radiometric maps interpret the relationship between hydrocarbon accumulations and the predictable movement of radioelements.

This research focused on identifying promising locations of hydrocarbon accumulation within the Gongola Basin using the Kolmani well 1 as a control. This was achieved with the application of several techniques on the radiometric data within the study area. This was further confirmed with the computation of DRAD values within the study area.

A. *Geology of the Study Area*

According to [20], the Gongola basin is the Northern Benue Trough's north-south trend. The Upper Benue Trough's rifting and the buildup of sizable sediment layers in several depocentres inside this NW-SE trending depression marked the beginning of this region's structural history at the start of the upper Cretaceous [21]. In the Gongola Basin of Nigeria's Upper Benue Valley, at latitude 10 °N and longitude 10 °E, is the Kolmani River-1 well (Fig. 1).

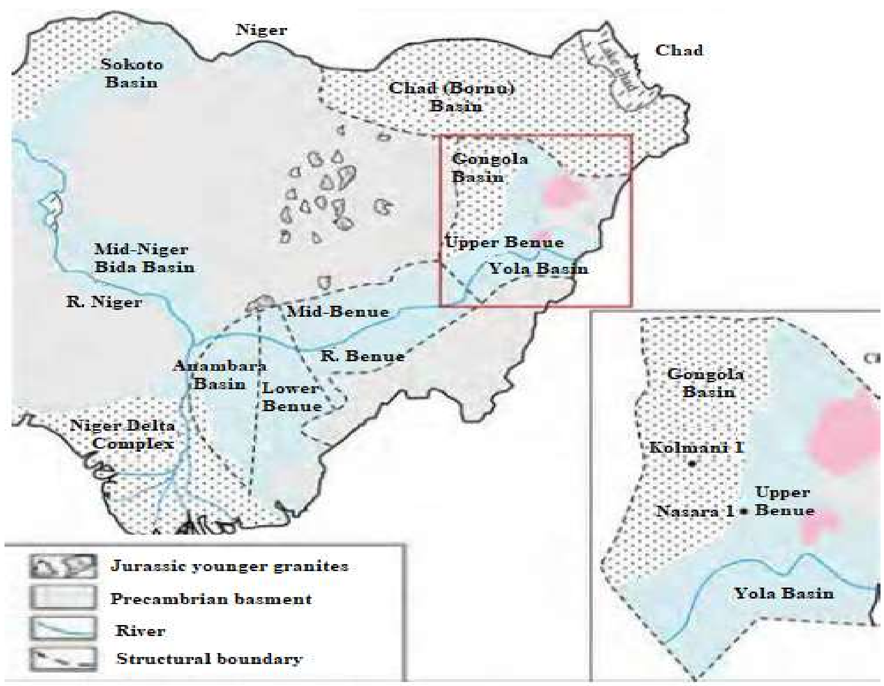

Fig. 1. Geology map of Nigeria with an insert that shows the location of Kolmani River -1 well (Edited) [22]

The Gombe, Pindiga, Yolde, and Bima Formations (Maastrichtian to Albian) are the four formations that the borehole penetrated. The coastal (deltaic) Gombe Sandstone, the youngest Cretaceous material in the Gongola Basin, unconformably overlays the pre-mid-Santonian stages in multiple locations [23].

Overlying the Precambrian Basement Complex in an unconformable manner, the continental Bima Sandstone is where the sedimentation process in the Gongola basin started. The granitic Basement Complex is where the Bima Sandstone originated. According to [29], it is composed of feldspathic sandstones and clays that transition upward into medium- to coarse-grained sandstones with less feldspar. The sandstone was split into three parts [30]: the Upper Bima (B3), Middle Bima (B2), and Lower Bima (B1). The Late Aptian - Early Albian formation was dated by palynological examination of the Bima Sandstone's outcropping strata [31]. The Yolde Formation is conformably overlain by the Bima Sandstone. This is made up of a shifting arrangement of shales and sandstones.

At the base, the sandstones are thinly bedded, and then there are alternating bands of shelly limestone and sandy mudstones [32]. The Pindiga Formation, which is primarily a marine shale facies with limestones at the base, comes after the Yolde Formation. The formation is thought to have been deposited in the Northern Benue Trough during early to late Turonian and Coniacian marine conditions. The lateral counterparts of the Pindiga Formation are the Gongila and Fika Formations [33]. The Gombe Formation, which consists of three main lithofacies, lies on top of the Pindiga Formation: 1. alternating beds of silty shales and fine-medium-grained sandstones with ironstone intercalations, overlain 2. medium-grained quartz arenite with occasional and iron oxide cement, and 3. Brick-coloured, fine- to medium-grained sandstone with tabular cross-bedding highlighted by layers and streaks of pure white sandstones. The Kerri-Kerri Formation is the newest in the Gongola basin. It is exemplified by the clays, siltstones, sandstones, and slightly dipping continental conglomerates that overstep into the Gombe Formation. Sediments infill into the tectonic structures of the Kerri-Kerri Formation causing the continental clastics to reach a thickness of around 320 meters because of the faulted and folded nature of the Gombe Formation [33]. Using pollen data, [34] dated the Formation to the Paleocene.

The Pindiga, Yolde, and Bima formations have historically been the only areas searched for petroleum source rock in the Gongola basin [21][24][25][26][27][28]. This was likely due to the premise that the Gombe formation is comparatively younger [23].

II. MATERIAL AND METHOD

A. Materials

Materials used for this study

The primary materials used for this study are aero-radiometric data (between sheets 151, Bara and 172, Futuk), and Oasis Montaj software.

B. Data Acquisition

The data were acquired by attaching a spectrometer to an aircraft. Fixed-wing aircraft, or less frequently, helicopters, fly in a grid-like pattern at a predetermined altitude, velocity, and line spacing to gather airborne radiometric data. To achieve the required resolution, the survey area must be significantly bigger than the target area and the line spacing must be thick enough [36]. Gamma energy is measured by onboard sodium iodide scintillation counters, and GPS position data is stored in the digital data stream. Depending on the speed of the aeroplane, channels for the overall gamma count, U, Th, and K are individually accumulated, often at one-second intervals that equate to 30 to 60 meters across the ground. Maps displaying the total count and specific radioisotope concentrations (equivalents for U and Th) are produced after the data are corrected for flight height, air temperature, humidity, cosmic noise, Compton scattering, and radon effects. Surficial variables including variations in lithology, soil type, wetness, vegetation, standing water, overburden thickness, terrain, and cultural impacts will almost definitely have an impact on the final data.

The airborne radiometric data used in this study (longitude 10.5ºE – 11ºE, and latitude 9.8ºN – 10.3ºN) to achieve the set objectives was sourced from the Nigerian Geological Survey Agency (NGSA) Abuja, Nigeria. The airborne radiometric dataset obtained was part of the airborne survey carried out between 2005 and 2009 by Fugro on behalf of the Nigerian Geological Survey Agency. The data were acquired and obtained 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 [35].

C. Methods

The production of ternary maps and isotope ratios are examples of conventional processing that helps to lessen surficial effects; however, more sophisticated processing is needed to improve the reliability of hydrocarbon detection. Subsurface hydrocarbon deposits over an otherwise radioactive Earth yield anomalously low total radiation patterns, as noted by [49], [50]. According to [37], whereas Th stayed constant, the U and K distributions were more trustworthy signals of hydrocarbons. On that basis, the following steps were employed to achieve the objectives of this study.

i. Produce maps displaying the spatial distribution of the concentration of Potassium (K), Thorium (eTh) and Uranium (eU)
ii. Produce a 1D plot showing the cross-sectional variation of the concentration of the three radionuclides over the Kolmani 1 oil well.
iii. Produce the normalization map of both potassium and uranium within the study area using the simplified thorium normalization method (STNM). To identify radiometric signatures connected to hydrocarbon accumulations in sedimentary basins, the STNM was created [37]. According to [35] it is one of the most effective models for the goal of development. [38] explain the "optimal" potassium and uranium value for samples using ab initio calculations based on thorium content, a lithological control. The fundamental premise is based on the observation that actions taken to modify the apparent concentration of comparable thorium also have predictable effects on the concentrations of uranium and potassium. The radioactive elements (K, Th, and U) should be in naturally occurring and constant amounts if hydrocarbons are absent [37], [41], [40].

As a guide for petroleum exploration, STNM has made a significant contribution to the delineation of hydrocarbons [61], [44], [42], [41], [62], [40], [45], [46]. Normalizing the thorium concentration will have an impact on the environment as well as attenuate the lithological units. Because of their comparable behaviours, uranium and potassium can be roughly predicted by using thorium values to ascertain their general associations [37]. Significant differences between the actual and projected concentrations of potassium and uranium must be caused by something other than lithology, soil moisture, vegetation, or counting geometry. It is feasible to identify potential hydrocarbon buildup by understanding these secondary impacts [39][37]. Plots of the field measure K (%) versus Th (ppm) and U versus Th (ppm) values for all stations were created. Using the [37] procedure, the equivalent concentration of uranium and potassium from the airborne radiometric spectral profiles of the study area can be normalized to the equivalent thorium data.

iv. Compute DRAD (Delineation of Radiometric anomalies) values for the study area; positive DRAD values are favourable indicators for subsurface hydrocarbon accumulations in an area [37]. Determining DRAD values of the study area requires the computation of K_i and U_i (see (1) and (2) respectively). These are achieved through the ratios of the mean K_S (%) to the mean eThs (ppm) and the mean eUs (ppm) to the mean eTh_s (ppm). The equations are given in (1) and (2).

$$K_i = \left(\frac{mean\ K_S}{mean\ eTh_S}\right) eTh_s \quad (1)$$

$$U_i = \left(\frac{mean\ U_S}{mean\ eTh_S}\right) eTh_s \quad (2)$$

Where K_i is the calculated equivalent thorium-defined potassium value from the station with the actual thorium value of eTh_s, and U_i is the calculated equivalent thorium-defined uranium value for that station.

Adopting the approach discussed above, the equations were calculated directly from the data, and quick field evaluations may be made without preparing the plots and restoring them to curve fitting. Deviation of the actual values from the calculated values for each station can be obtained from (3) and (4) [37]:

$$KD\% = (K_s - K_i)/K_s \quad (3)$$

$$eUD\% = (eU_s - eU_i)/eU_s \quad (4)$$

where K_s and eU_s are the measured potassium and equivalent uranium values at the station respectively.

$KD\%$ and $eUD\%$ are the relative deviations expressed as a fraction of the station values. From experience, KD% yields small negative values and $eUD\%$ yields smaller negative or sometimes positive values over the hydrocarbon accumulations [37]. Emphasizing these two relationships, [37] defined a new parameter, called DRAD given by (5).

$$DRAD = eUD\% - KD\% \quad (5)$$

III. RESULTS AND DISCUSSION

The spectrometric map showing the variations of the concentrations of the three radioelements within the study area was produced (Fig. 2 - 4). Light oil and gas micro-seeps, bacterial activity, groundwater movement, redox boundaries, and pH changes brought on by the physical and chemical disequilibrium between oil and gas accumulations with their host rocks combine to produce the superficial radiation patterns associated with buried hydrocarbon deposits [49], [54], [55], [56], [48], [58]. The physical, chemical, and biological features of rocks and soil near the surface are changed over millions of years by the diagenetic properties of hydrocarbons. Reduced levels of potassium, thorium, and uranium have been seen in oil-producing zones (OPZs), and this phenomenon has been attributed to increased natural radioelement leaching brought on by hydrocarbon-generated groundwater acids [47], [51]. The Kolmani well 1 exhibits the same characteristic; low concentrations of potassium, thorium, and uranium (Fig. 2 – 4).

The concentrations of the radioelements around the Kolmani well 1 were observed to trend in the NE direction, although, more prominent in the maps of potassium and thorium (Fig 2a and b), it reflects the lithology of the area [52]. The 1D profiles extracted from the maps, (Fig 2 – 3), were drawn perpendicular to the trend to visualize the actual nature of the radioelements at the location of the Kolmani well 1.

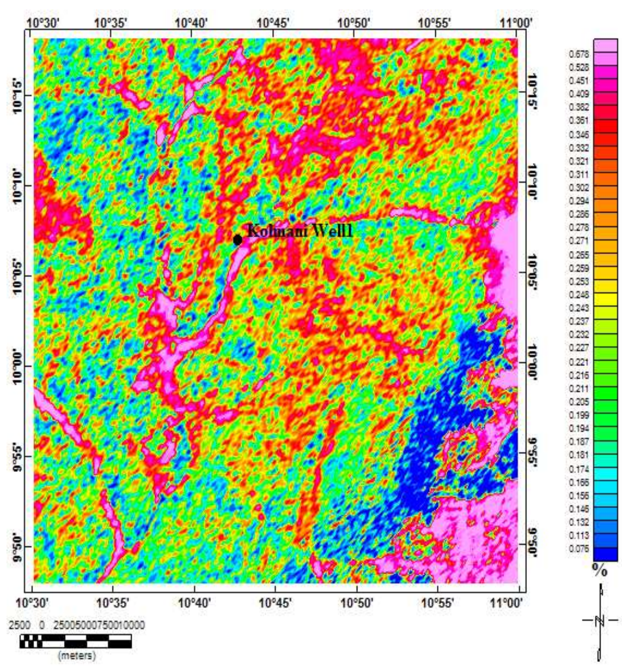

Fig. 2. Spectrometric map showing the variation of potassium concentration in the study area.

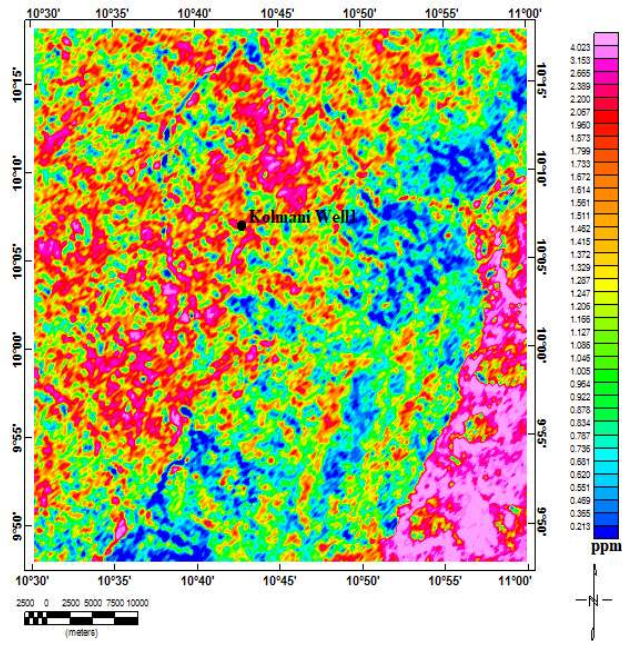

Fig. 3 Spectrometric map showing the variation of uranium concentration in the study area.

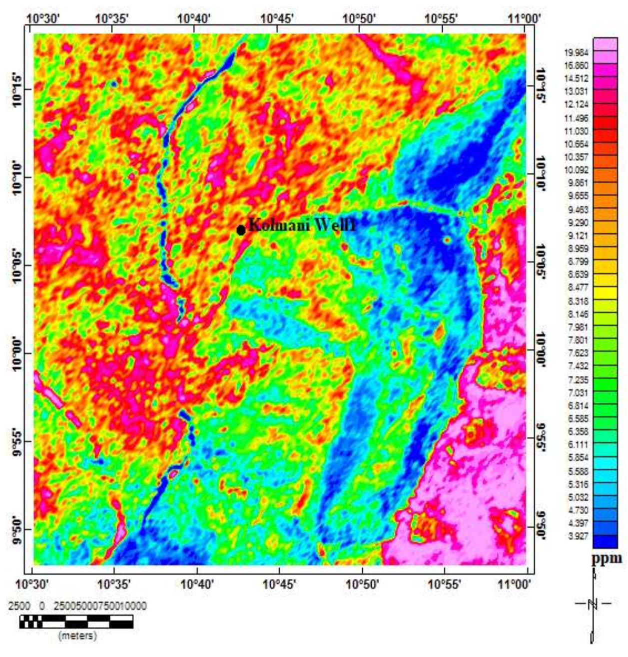

Fig. 4. Spectrometric map showing the variation of thorium concentration in the study area.

The concentration of the three radioelements dip at the location of Kolmani oil well 1 (Fig. 5) which agrees with the norms [53][47][37][51].

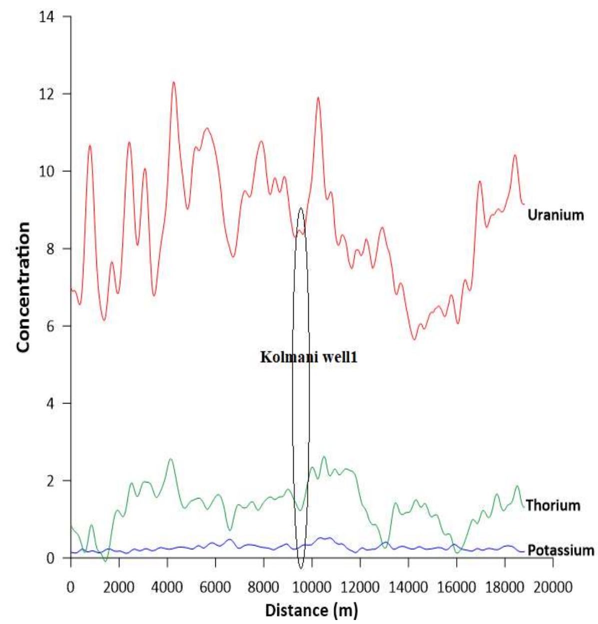

Fig. 5. 1D plot of the three radioelements drawn parallel to the prominent NE trend around the Kolmani oil well 1 location.

The valent state of uranium affects its solubility and mobility [59]. U+6 is carried to the surface by micro-sized gas bubbles released under pressure from a hydrocarbon deposit, where it is reduced to U+4 by organic compounds, precipitates, and becomes immobile. The gas bubbles escape nearly vertically through a network of joints filled with groundwater and bedding planes connected to differential compaction. The pH of groundwater affects K. Low pH hydrocarbons produce carbonic and organic acids that break down clay minerals, releasing K into rising groundwater through potential contact with redox electrochemical convection cells. In the presence of hydrocarbons, micro-seepages, groundwater movement, and convection cells, this is thought to be more stable. Geophysics can successfully map geochemistry in this condition because of the complex interactions between the three radioelements in the weathering environment that produce different radioactive patterns on the surface above hydrocarbon accumulations.

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 [60]. These characteristic anomalies were observed around the Kolmani oil well 1 in the normalized potassium and uranium maps (Fig. 6 and 7). This known characteristic was then used to identify locations with potential for hydrocarbon accumulation, thus, four locations were notable (Fig. 8).

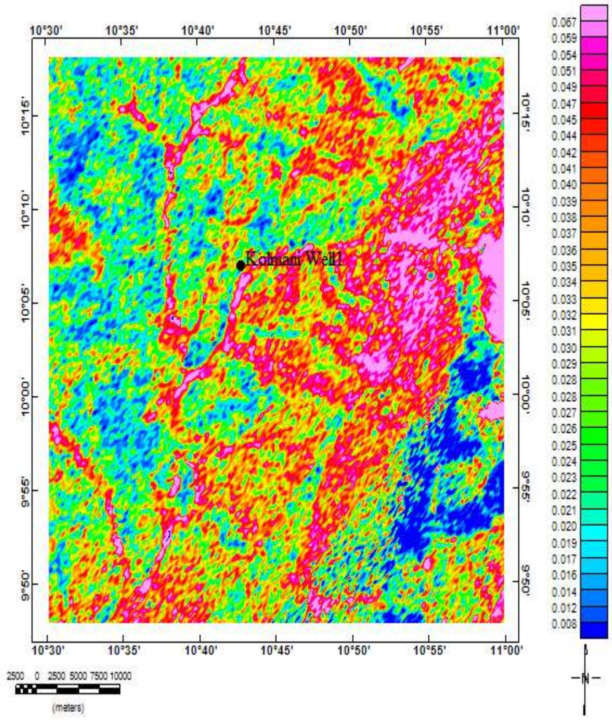

Fig. 6. The normalized potassium map of the study area.

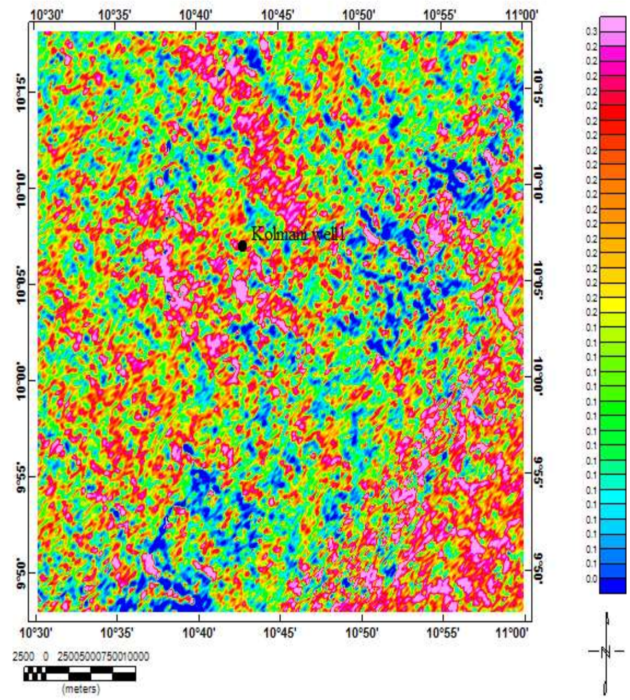

Fig. 7. The normalized uranium map of the study area.

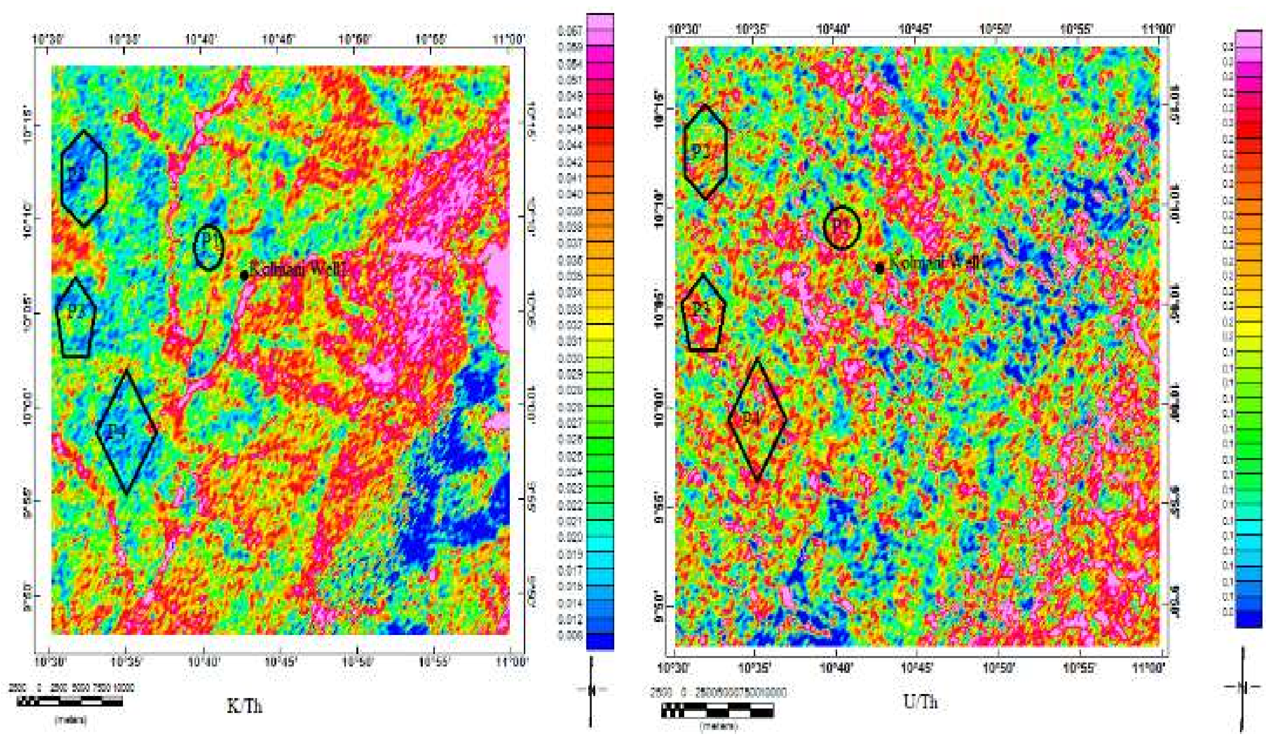

Fig. 8 Maps indicating locations with promising hydrocarbon accumulation based on the normalization of (a) potassium and (b) uranium with thorium.

DRAD technique was then used to confirm the viability of the four identified locations for hydrocarbon accumulations. Interestingly, the four locations and Kolmani well 1 recorded positive DRAD values (see Fig. 9), a pointer to hydrocarbon accumulation.

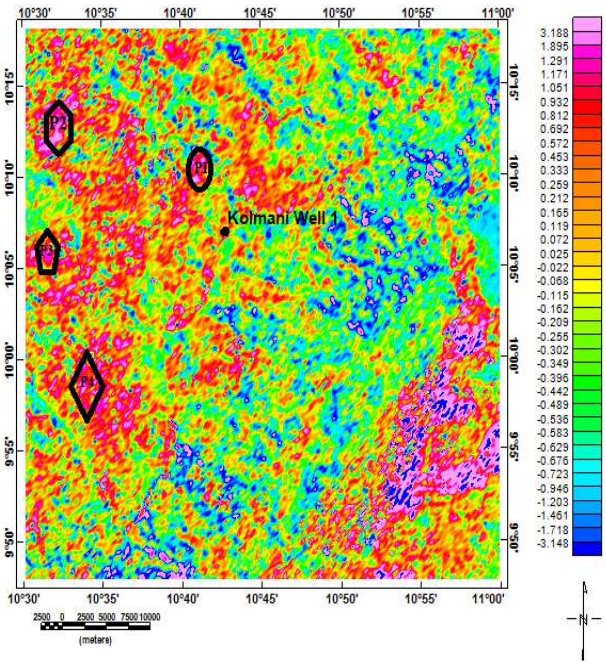

Fig. 9. DRAD map of the study area showing four promising locations for hydrocarbon accumulation.

IV. Conclusion

The application of various techniques on the radiometric data covering part of the Gongola basin hosting one of the prolific oil wells in the inland basins was intended to emphasise their effectiveness in determining promising hydrocarbon accumulation locations. In addition, various methods adopted in this research were mainly for identifying new locations with potential hydrocarbon potential and the Kolmani well 1 location as a control.

The results were promising as all the methods consistently indicated that four identified locations were probable locations for hydrocarbon accumulation. This research has, as a result, limited further exploration for hydrocarbon in the study area to the four locations, thus, saving cost and reducing the risk in hydrocarbon projects.

Availability of Data

Data can be accessed upon request.

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