# Prediction of Hydrocarbon Potentials of the Idemili River Basin, Southeastern Nigeria Using Hybrid of Geophysical Methods

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## ABSTRACT

This study used a combination of geophysical techniques with a focus on magnetic and satellite imagery features to forecast the hydrocarbon potentials of the Idemili River Basin, Southeastern Nigeria. The hybrid applications' methodology improves the consistency and simplicity of identifying important structural and stratigraphic traps for the accumulation of hydrocarbons within the study region. Four aeromagnetic datasets acquired from Nigerian Geological Survey Agency were merged and analyzed using various standard techniques including spectral analysis. In order to identify and describe the stratigraphic traps in the area, the study also used Google Earth to visualize satellite imagery in three dimensions of the Earth. The outcome shows that the study area has varying magnetic intensity, with residual anomalies ranging from -24.7 nT to 167.3 nT. The Rose diagram and the visual appearance of the derivative and lineament maps show that the region is severely fragmented, with large structures trending in the NE-SW and smaller structures in the E-W and NW-SE directions. The results of the spectral analysis demonstrate the variation in sedimentary thickness, with an average thickness of 6.24 km in the study area. A major channel and alluvial fans were discovered in the research region as a result of the geomorphological analysis of the satellite imagery in the area. The discovered significant channel feature has a sinuosity of 2.31, a meandering length of 739 m, and a northwest-southeast direction. Three different Idemili fan types are also shown by the results: base, center, and outer fans. The research demonstrates that a fluvial depositional environment is connected to the study area. The study concludes that the presence of stratigraphic traps, high sedimentary thicknesses, and subsurface lineament structure systems could greatly enhance the possibility of hydrocarbon accumulation in the study area.

**Keywords:** Aeromagnetic Data, Spectral Analysis, Rose Diagram, Idemili Fan and Fluvial Environment.

## INTRODUCTION

Geophysical methods usually measure the physical properties of materials that can be used to infer information about the surface and subsurface of the Earth (Kearey, 2002). Generally, geophysical methods are classified into two methods: passive (natural) and active (artificial) method. According to Kearey (2002), the passive methods detect variations within the natural fields associated with the earth, such as gravitational, magnetic, electrical and electromagnetic fields. But the active methods like the seismic and some electrical methods detect artificially generated signals transmitted into the ground and then modify the received signals in ways that are characteristic of the materials through which they travel. It is good to note that the active methods can yield better and detailed information of the subsurface geology but very complex in terms of data acquisition than the passive methods.

In this study, two aspects of the passive methods were used, namely, the magnetic method (a precise aeromagnetic survey or data) and the electromagnetic method (remote sense, geospatial, or Google Earth satellite imagery). According to Chinwuko *et al.* (2023); Edunjobi *et al.* (2021), an aeromagnetic survey is a method of geophysical prospecting that offers imagery into the Earth's subsurface by identifying anomalous sources resulting from the magnetic properties of underlying rock units. In the view of Ngoh *et al.* (2017), an aeromagnetic survey can be defined as that type of geophysical survey carried out using a magnetometer aboard or towed behind an aircraft. The principle is similar to a magnetic survey carried out with a hand-held magnetometer but allows much larger areas of the Earth's surface to be covered



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quickly for regional reconnaissance. In the aspect of Google Earth satellite imagery, Malarvizhi *et al.* (2016) viewed Google Earth Imagery source as open sources which offer clear view of earth's surface attributes that can be used for multiple applications including hydrocarbon attributes.

But in order to match the rate of hydrocarbon production and demand to the rate of new discoveries, Chinwuko *et al.* (2015) stated that in recent years, the focus of hydrocarbon exploration has shifted from structural traps to stratigraphic traps. The present investigation employed non-seismic techniques to envisage potential structural and stratigraphic characteristics that may facilitate the mapping of traps capable of containing massive hydrocarbons in the investigated region. As a result, big traps that would produce a higher value investment ratio are now the focus of hydrocarbon investment.

Finally, the study used a combination of geophysical techniques with a focus on magnetic and satellite imagery features to forecast the hydrocarbon potentials of the Idemili River Basin, Southeastern Nigeria. The hybrid applications' methodology improves the consistency and simplicity of identifying important structural and stratigraphic traps for possible accumulation of hydrocarbons within the study region.

## LOCAL GEOLOGY OF THE IDEMILI RIVER BASIN

Idemili River Basin is located in the Southeastern Nigeria and it is underlain by Ogwashi Asaba Formation and Nanka Sands of Amerki Formation. These geological formations fall within the Niger-Delta Basin (Fig. 1)

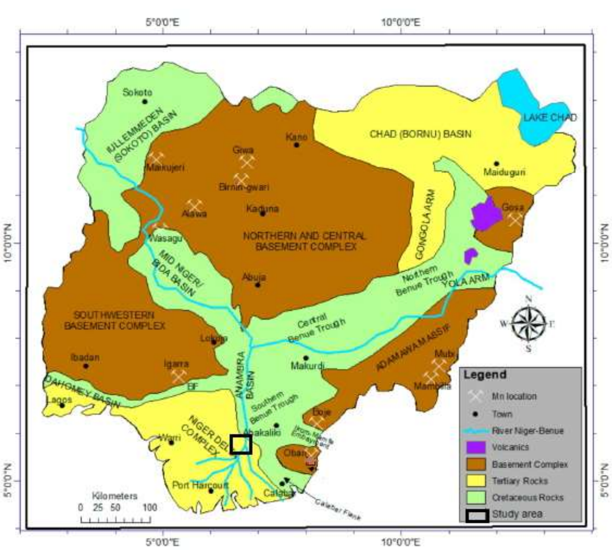


**Figure I:** Map of Niger Delta showing the study area (After Omang *et al.,* 2020).

according to Nwajide (2022) and Okon *et al.* (2022). In the words of Chinwuko *et al.* (2015) and Izuaka (2023), it is ranked among the world's most prolific petroleum producing Tertiary Deltas.

Furthermore, Nwajide (2022) stated that Nanka Sand of Eocene Epoch is a member of Ameki Formation which consists of friable, fine to medium sand, with intercalations of mudstones. The Nanka Sands is overlain by the Ogwashi- Asaba Formation with geological age of Oligocene – Miocene Epoch (Nwajide, 2022). It comprises of white and/or pink clays, carbonaceous mudstone, shales, seams of lignite along with cross-bedded sands.

## METHODOLOGY

The hybrid applications' methodology improves the consistency and simplicity of identifying important structural and stratigraphic traps for the accumulation of hydrocarbons within the study region. The methods involved include integration of the four aeromagnetic data sheets, production of magnetic anomaly map, generation of structural maps, analysis and modelling of magnetic anomaly data. The derived maps were subjected to various transformation and enhancement procedures. The purpose of these procedures was both for enhancement and assessment of consistency of the various categories of anomaly and features. The spectral analysis technique was found to be most suitable for sedimentary thickness calculation in this study, and was adopted for the purpose.

In order to identify and describe the stratigraphic traps in the area, the study also used Google Earth to visualize satellite imagery in three dimensions of the Earth. Then, major structural traps such as faults and stratigraphic traps alluvial fans and loops were interpreted in both magnetic and satellite imagery data. Finally, an integrated depositional model was constructed using all the interpretations and findings.

## RESULT AND DISCUSSION

### Aeromagnetic Findings

The quality interpretation of the residual anomaly map of the study area reveals complex pattern of magnetic signatures of both short and long wavelengths (Fig. 2). This varying amplitude of the anomaly suggests varying magnetic intensities from different causative sources as established by Okonkwo *et al.* (2021) and Chinwuko et al. (2012) which are evident in the southern, northwestern and northeastern parts of the study area. The underlying basement across the area range possess magnetic intensity ranging from -24.7nT to 167.3nT. These magnetic values depict majorly of low intensity signifying possible high sedimentary thickness which is in accordance with the known geology map of the study area produced by Nwajide (2022) and Omang *et al.,* (2020). Moreover, the alignment of closed anomalies within these areas suggests presence of underling magnetic bodies.

The analytical map generated (Fig. 3) depicts that there is set of northeast (NE) to southwest shear fractures as a locally diffuse structure controlling the sedimentary packages on the central, northern and northeastern parts of the study area which is fractured by intersecting structures within the study area.

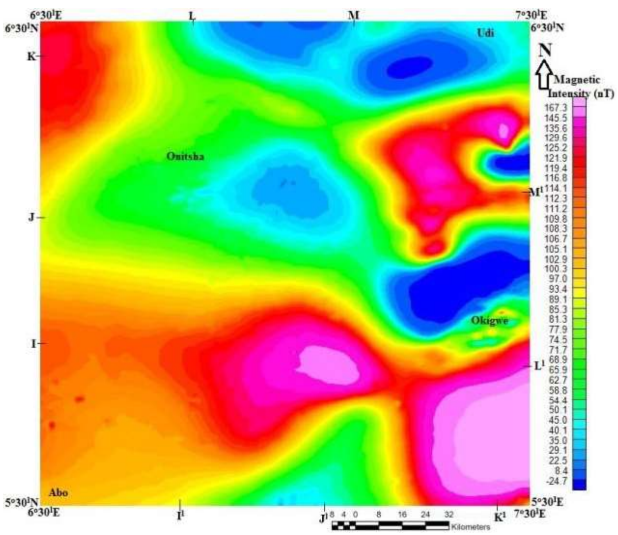


Figure 2: Residual anomaly map of the study area showing the selected profiles for this area.

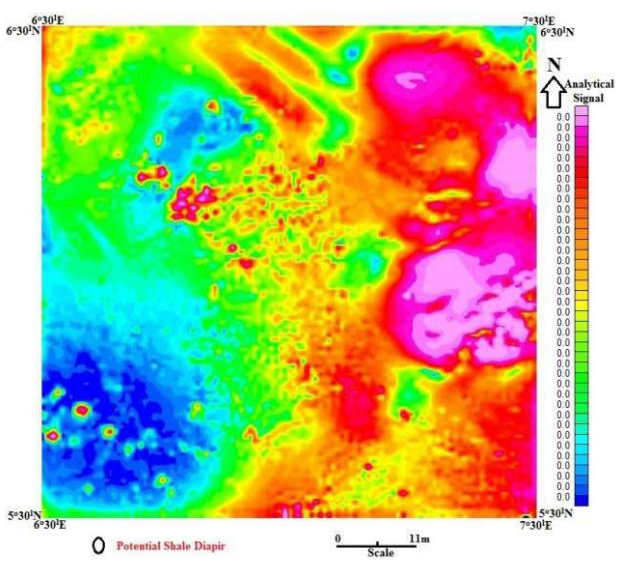


**Figure 3:** Analytical map of the study area.

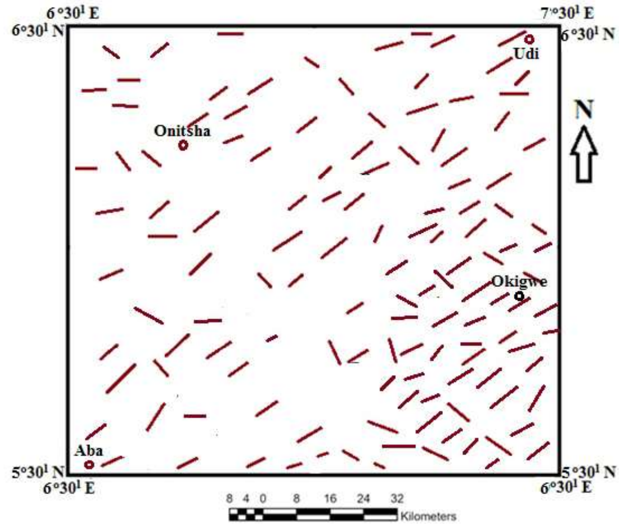


**Figure 4:** Magnetic Lineament Map.

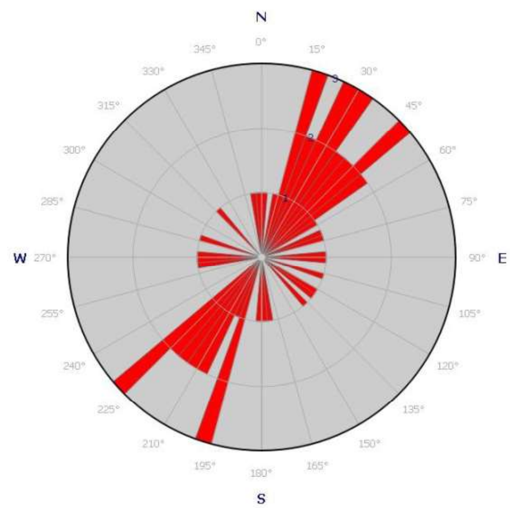


**Figure 5:** Structural trend in the area.

A magnetic lineament map was generated in order to aid visibility, enhancement and recognition of major trends in the area (Fig. 4). As indicated on the geology map of Nigeria, the basement and Benue Trough boundaries are sub-parallel limbs of the NE (Pan-African) fold system (Nwajide, 2013).

The magnetic lineament map (Fig. 4) was generated from the integration of the magnetic and analytical maps of the area.

The map shows clearly the structural attribute maps with the major structural trends of NE – SW direction with minor of trends of E - W and NW - SE directions. This result is in corroboration with earlier works carried out within the study area and other portions of the adjoining basement terrains (Chinwuko *et al.* 2023, Lar *et al.,* 2023; Okon *et al.,* 2022; Omang et al., 2020; Usman *et al.,* 2016). Juxtaposing these lineaments on the geological map of the study area, it depicts that the structural lineaments were slightly less concentrated within the Createaceous sedimentary rocks compared to the basement complex rocks around Onan Massif areas (Southeastern part of the study area). The high concentration of structural lineament in the area southeastern part portrays intense tectonic activity that affected the basement complex rocks and its adjacent Cretaceous packages.

Furthermore, the Rose Diagram of the study area (Fig.5) depicts that there are regular structural patterns of NE-SW with minor trend of E – W and SE-NW trends. This deduction can be attributed in dating some of the past events that have yielded the existing rocks and structures (Anudu *et al.,* 2012). In line with the works of Nwajide (2022) and Obaje (2009), one can envisage that the study area is regarded as Pan-African Orogeny while the E-W and NW-SE is associated with Pre-Pan-African Orogeny.

Quantitatively, the twenty one magnetic anomalies identified along the five selected profiles in the study area (Fig. 2) were analyzed using spectral analysis in order to obtain the sedimentary thickness across the area. The spectral analysis result depicts sedimentary thickness to be between 0.87 to 7.16 km with average thickness of 6.24km which conforms to the works by Chinwuko et al. (2023) and Okon *et al.* (2022). Thus, the distribution map of the sedimentary thicknesses generated depicts that there are lower sedimentary piles around the southeastern part (Okigwe region) and northwestern part of the study area while, at other parts of the area such as Onitsha, Abo and Udi areas have higher sedimentary piles (Fig. 6).

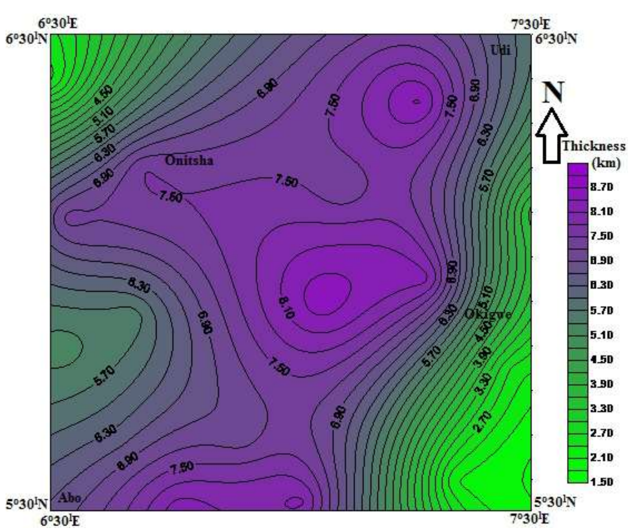


**Figure 6:** Sedimentary thickness map acrossthe area.

**Satellite Imagery**

The result of geomorphological analysis of the satellite imagery of the study area revealed two major stratigraphic traps namely; channel and alluvial fans (Fig. 7 -9). The discovered significant channel feature has a sinuosity of 2.31, a meandering length of 739 m, and a northwest-southeast (NW-SE) direction (Fig. 8). This channel identification is plausible because sand-rich deposits of channels can form major reservoir target (Chinwuko *et al.* 2015).


**Figure 7:** Geomorphic map of Idemili River.


**Figure 8:** Identification of sinuous channel.

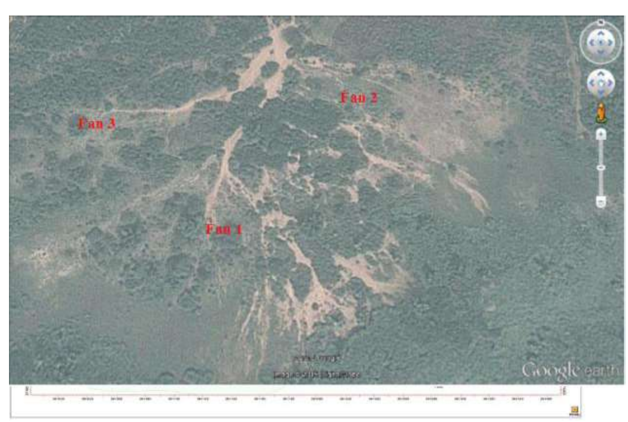


**Figure 9:** Identification of Idemili River fan.

**Depositional model of Idemili fan**

Considering that the study area lies within the Equatorial Monsoon climatic belts of Nigeria which originate from the southwest monsoon winds that comes from the Atlantic Ocean usually causes much rainfall in the area during the raining season resulting in an average rainfall of 1850mm/year (Ejiagwa *et al.,* 2017; Ileoje, 1985). Thus, in the Early Eocene to Miocene Epoch, the idemili River was able to formed three different alluvial fans which can be distinguished into base, center, and outer fans (Fig. 10 -11). The geomorphological examinations of these fans show that the deposition mechanisms of these fans are closely related to the conventional alluvial fans formation. The rate of formation of Idemili fans is as a result of huge deposition of sedimentary materials through weathering and transportation means of Idemili River.

Additional, the depositional model depicts strongly the coarsening upward sequence which is associated with the prograding depositional environment (Fig. 11). The Center facies of the Idemili Fans serves as a transition zone from outer to base fans, while the sediments become finer (Fig. 11). Invariably, the middle fans consist of medium-coarse sandstone with sedimentary structures formed by the fluvial process. The outer-fan sediments appear only on a small scale and in front of the channels as a band (Fig. 11). These outer fans conglomerate content decreases greatly towards the base of the fan ( Fig. 11) and according to Song *et al.* (2020) and Xin *et al.* (2011), the coarse river sediments may constitute the main reservoir in the study area The base fans seem to contain the finest sediments such as shale which occur at the bottom of the fan. Generally, the model demonstrates that a fluvial depositional environment is prevalent in the study area.

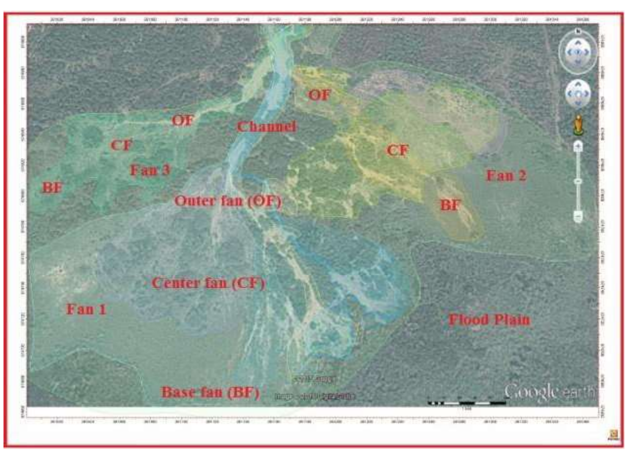


**Figure 10:** Characterization of Idemili fans

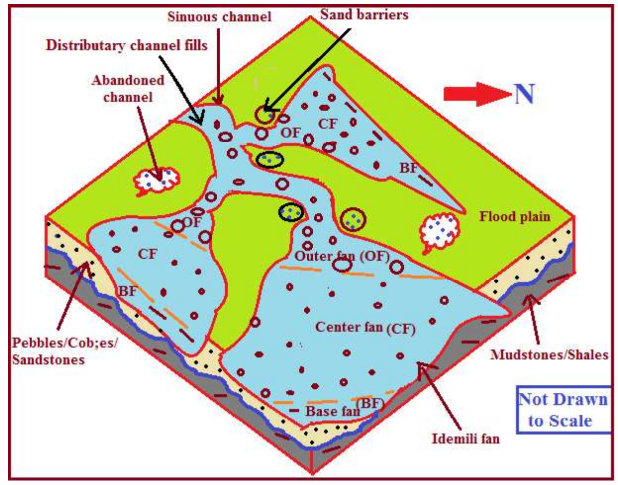


**Figure 11:** A fluvial depositional model of the study area.

**Implications of the findings on Hydrocarbon Accumulation**

The deduced subsurface magnetic lineament structures trending majorly in the NE-SW direction within the study area conforms to the basement structures of Nigeria. The existence of such sub-surface/deep-seated extensive lineament structure systems could serve as pathways for fluid flow such as hydrocarbon, water, and brines within the study area (Chinwuko *et al.,* 2012; Lar *et al.,* 2023).

Furthermore, the computed sedimentary thickness revealed an average of 6.24km across the study area conforms to the general standard according to Wright (1985) and Chinwuko *et al.* (2012) for possible hydrocarbon accumulation since the average thickness is above 2.10km.

In addition, the presence of sinuous channels within the study area can serve as a significant conduits for the movement of sediments from the outer fans to base fans and these channels may host significant hydrocarbon reserves within the area (Chinwuko et al., 2015, Mayall *et al.* 2006). Also, the sedimentary facies zones identified within the idemili River fans have a great impact on hydrocarbon accumulation because the qualities and constituents of the fans in the area is highly plausible for hydrocarbon accumulation. These fans especially, the middle/center fans possess good attributes for reservoir such as thick sand bodies along with some good sedimentary structures as shown on the depositional model. Finally, the interpreted outer fans in the study area are equivalent to a transitional facies between the Idemili fan and the sinuous channels which is of great importance in hydrocarbon accumulation.

## CONCLUSION

The study concludes that the hybrid of aeromagenetic and satellite imagery methodology improves the consistency and simplicity of identifying important structural and stratigraphic traps for the accumulation of hydrocarbons within the study region. The outcome shows that the study area has varying magnetic intensity, with residual anomalies ranging from -24.7 nT to 167.3 nT. The the visual appearance of the derivative and lineament maps show that the region is severely fragmented, with large structures trending in the NE-SW and smaller structures in the E-W and NW-SE directions. The results of the spectral analysis demonstrate the variation in sedimentary thickness, with an average thickness of 6.24 km in the study area. A major channel and alluvial fans were discovered in the study area as a result of the geomorphological analysis of the satellite imagery in the area. The discovered significant channel feature has a sinuosity of 2.31, a meandering length of 739 m, and a northwest-southeast direction. Three different Idemili fan types are also shown by the results: base, center, and outer fans. The research demonstrates that a fluvial depositional environment is connected to the study area. The study concludes that the study area could possibly host hydrocarbon accumulation due to the prevalent features favouring petroleum generation.

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