Hydrocarbon Prospect Evaluation from Remote Sensed Data in Parts of Lower Benue Trough

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ABSTRACT: *The search for hydrocarbons in parts of the lower Benue basin has remained comatose because of poor discoveries. The basin has attracted focused attention in the recent because of the continued discovery of commercial hydrocarbons in the contiguous basins of Chad and Niger Republics and Sudan. However, data from drilled wells revealed a number of continuous organic rich stratigraphic intervals with potentials for both oil and gas generation. With the rising global energy demand and uncertainties in supply, explorations are taking new dimensions with the adoption of new technologies. Remote sensing offers an attractive, robust and innovative reconnaissance technique that compliments the geophysical methods in hydrocarbon exploration. In the present study, a satellite image-based analysis was conducted for extracting surface lineaments and terrain attributes for hydrocarbon prospect evaluation in parts of the lower Benue basin. Advanced space borne thermal emission and reflection radiometer global digital elevation model (ASTER GDEM) and Landsat 8 OLI/TIRS data were used. Results revealed that lineament distribution, density and orientation vary across the study area. The tectonic highs (escarpment) have high prevalence of lineaments and lineament density than the lowlands/valleys, suggesting a structurally deformed area. The NE-SW is the most dominant lineament orientation and the major tectonic feature that control the structuration of the study area, while NW-SE, N-S and E-W lineament orientations are less dominant. Terrain attributes were partly lineament-controlled and lithological and could be related to the development of petroleum entrapment structures. Hydrocarbon prospect zones were delineated in medium to high lineament density areas, where lineament intersections and connectivity capable of trapping hydrocarbons is high. Therefore, Agwu, Awka, Enugu, Nsukka, Udi and Ukehe located on the escarpment are preferred prospect areas than Adanu, Nkalagu and Igumale in the flanking lowland/valley areas for detailed hydrocarbon exploration. Correlation of lineament density and surface hydrocarbon seepage in parts of the basin, revealed that high lineament density correlates with known location of hydrocarbon seepage in the study, indicating the connectivity of these lineaments with deep seated structures.*

KEY WORDS: remote sensing, escarpment, hydrocarbon, lineament, Benue trough.

INTRODUCTION

The Lower Benue basin, a distinct southern portion of the Benue rift structure in Nigeria, is the failed arm of an aulacogen formed at the opening of the South Atlantic Ocean during the separation of the African plate and the South American plate in the early Cretaceous. It is a linear intracratonic rift basin with Cretaceous – Tertiary sediments deposited in the Abakaliki, Anambra and Afikpo depo belts (Benkhelil, 1987; Akande, et al., 2012). The search for commercial hydrocarbon deposits in the basin dates back to the late 1930's. Reports of field and laboratory studies revealed that the basin possesses the requisite structural elements and stratigraphy similar to the contiguous basins of Chad and Niger Republics and Sudan, where commercial hydrocarbon discoveries have been made (Genik, 1993; Schull, 1988; Akande, et al., 2012, Abubakar, 2014).

However, discovery of hydrocarbons in commercial quantity in the lower Benue basin has remained unsuccessful due to complexities in geology and burial history. Previous drilling campaigns in the basin yielded characteristic dry wells in most of the cases. Data from drilled wells revealed a number of organic rich stratigraphic intervals (Cenomanian to Lower Maastrichtian formations), with proven potentials as oil and gas source rocks. The stratigraphic continuity of these intervals across the basin suggests their potentials for both oil and gas generation if thermally mature. There is therefore, the need for more detailed exploration for petroleum in the basin (Ekweozor and Unomah 1990; Obaje et al., 2004; Akande et al., 2012).

With the rising global energy demand and advancements in exploration tools, exploration for hydrocarbons in the lower Benue basin has taking a new dimension. The use of geophysical methods is often judged too expensive and time consuming especially, at the reconnaissance stage. Remote sensing imagery therefore, offers an attractive, robust and innovative technique that compliments the conventional geophysical methods in hydrocarbon exploration. Remote sensing detects and monitors the physical, temporal and spatial characteristics of the earth's surface and atmosphere by measuring reflected or scattered and emitted electromagnetic radiation using active and passive sensors on varied platforms at distance from the target.

In hydrocarbon exploration, remote sensing relies mostly on its application in the identification of subsurface topographic and lineament structures favorable for exploration (Gunn, 1997; Bedini, 2011; Prabaham et al., 2012). The method has the major disadvantage of not detecting hydrocarbon reservoirs directly because of its limited depth of penetration. However, shallow linear and topographic features which are reflections of deeper structures, lithologic variations and hydrocarbon seepage relating to hydrocarbon potential zones can be detected. The accuracy of the technique depends largely on the quality of data, processing and interpretation techniques.

The study area lies in the lower Benue basin and delineated by latitude 6°00′N–7°00′N and longitude 7°00′E–8°00′E (Fig. 1), covering most parts of Anambra, Benue, Ebony and Enugu

States. The area is characterized by mixed biomes and rainfall is at its peak in June and low in November with average daily temperature of $32C^0$.

Several authors have worked on remote sense data for application in hydrocarbon exploration in both old and new fields (Lillesand et al., 2015, Adiri et al., 2017 and Javhar et al., 2019). These authors extracted structural lineaments and generated terrain attributes such as drainage network, normalized difference vegetation index (NDVI), and elevation maps from remote sense data integrated with the geographic information system (GIS) technique, to evaluate hydrocarbon prospects in their studies. Their studies revealed explicitly the complimentary role remote sensing technique plays in hydrocarbon exploration vis a vis, the geophysical methods.

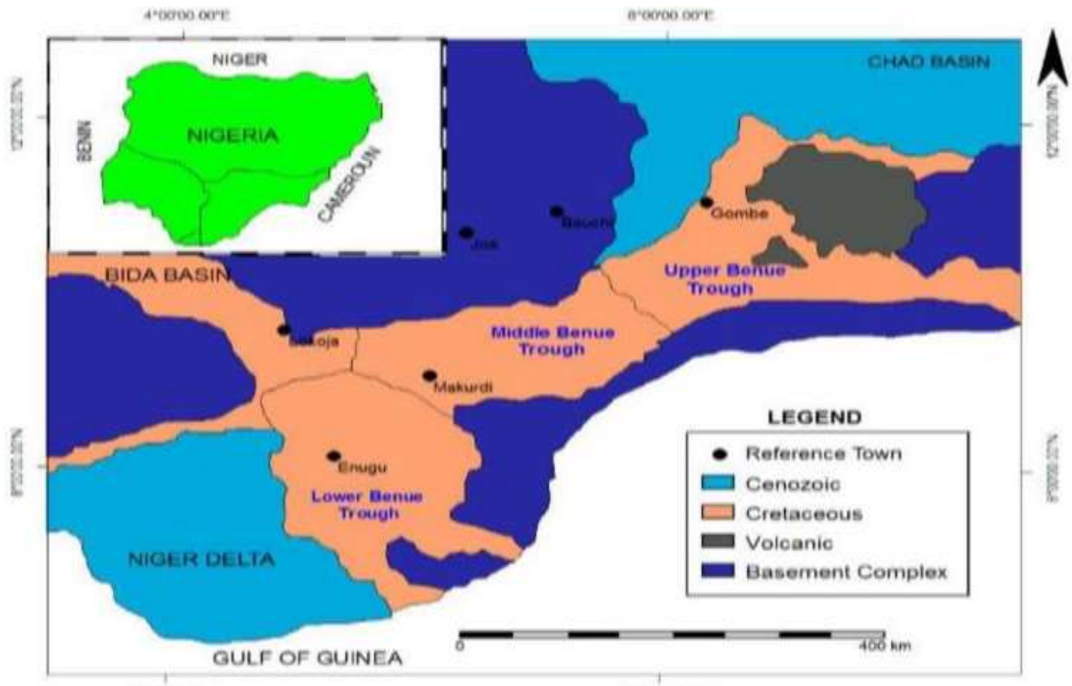

Figure 1: Location map of the study area (after Jauro, et al., 2008 and Cyril, 2019).

Surface deformations and faulting are probably the most common linear geologic features in the lower Benue basin. Typically, lineaments are mappable faults, joints, shear zones, intrusions, and dykes on the earth surface. They are essentially weak subsurface zones developed in areas of high stress or strain states following pressure and tectonics and have been proven to link directly with the formation, movement and trapping of hydrocarbons (Prabaham et al., 2012). Terrain attributes are surface geologic expressions of the underlying basement geology and relate directly with the structural lineaments.

However, relevant works in the literature on the application of remote sensing in hydrocarbon exploration in parts of the lower Benue basin remains scanty. The present study therefore, is aimed at integrating lineaments and terrain attributes extracted from remote sense data for hydrocarbon prospect evaluation in parts of the lower Benue basin.

Geology of the Study Area

The study area falls within the Abakaliki, Anambra and Afikpo geological belts in the lower Benue basin. The basin is underlain by thick pile of sedimentary rocks from early Cretacous -Tertiary, with intra-sedimentary igneous intrusions from the underlying Precambrian basement. The Basement Complex consist of essentially granitic and magmatic rocks which outcrop mostly in the eastern portion of the study area (Ofoegbu and Onuoha, 1990).

The stratigraphic sequence of the lower Benue basin range in age from the Aptian to mid Eocene. It is comprised of the Asu River Group, Eze-Aku, Awgu, Nkporo Group, Mamu, Ajali, Nsukka, Imo and Bende-Ameki Formations (Figure 2). At least two potential petroleum systems exist in the basin: the Lower Cretaceous petroleum system likely capable of both oil and gas generation and the Upper Cretaceous petroleum system that could be mainly gas-generating. Structures favoring the formation of petroleum traps are typical of those related to rift tectonics and include

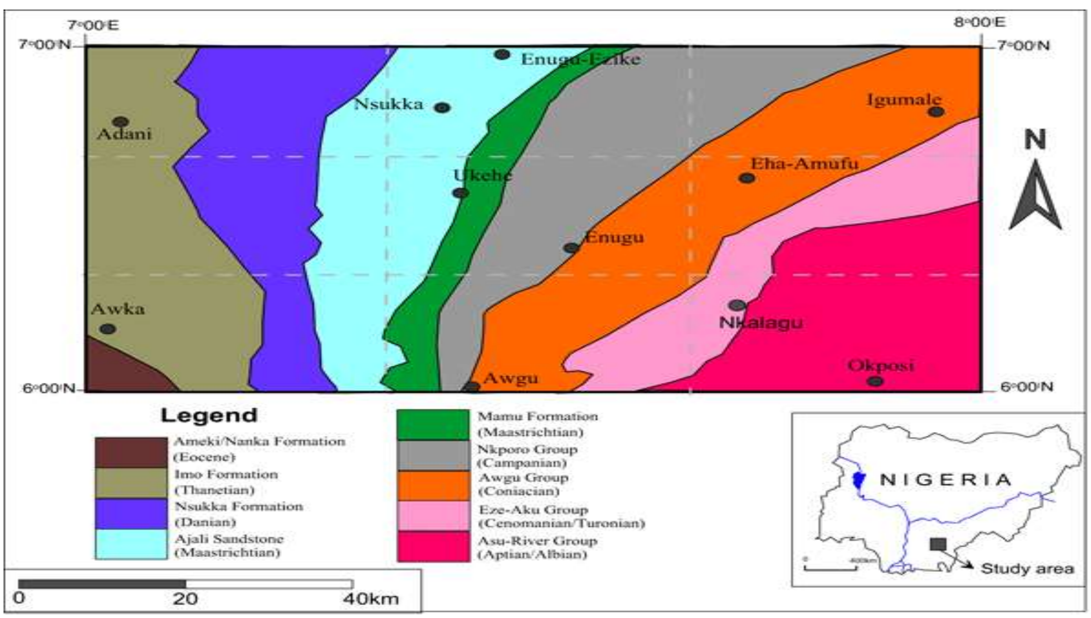

Figure 2: Geologic Map of the Study Area (After Anyadiegwu et al., 2017).

horsts and grabens, large scale transgressional anticlines, inverted fault blocks and drag folds amongst others (Benkhelil, 1987; Ekweozor and Unomah 1990; Obaje et al., 2004; Akande et al., 2012).

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METHOD OF THE STUDY

In the present study, lineaments were extracted from Landsat-8 OLI/TIRS and Global Digital Elevation Model (GDEM) data on 1:50,000 scale. Data enhancement techniques such as filtering operations, were applied to data to enhance lineament extraction. Structural lineaments were identified and mapped using PCI Geomatica 14.0 and subsequently, an orientation analysis via rose diagram were generated using Rockworks 15 to delineate the basic structural trend.

Furthermore, elevation map of the area was generated using the ASTER digital elevation model (DEM) data, while drainage and NDVI maps and overlays were generated using ArcGIS 10.5. These were to guide in the delineation of favorable areas for exploration. Finally, visual interpretation method was adopted and the lineament was correlated with the elevation, drainage and NDVI maps to establish relationships and delineate probable hydrocarbon zones in the study.

PRESENTATION OF RESULTS

Results of the processed remote sense data integrated with GIS technique are presented in the form of maps for analysis. These are the lineament, lineament density and rose diagram, as well as drainage network, elevation and NDVI attribute maps. The maps were visually inspected, analyzed and interpreted for indications of hydrocarbon prospects in parts of the lower Benue Basin.

Elevation Analysis

The elevation of the study area varies from 11 to 591m above sea level (Figure 3). It is characterized by tectonic highs (escarpment) flanked by lowlands/valleys. Awka, Agwu, Enugu, Nsukka, Udi, and Ukehe areas lie on the escarpment, while Adani, Igumale and Nkalagu areas lie in low elevation. The escarpment trend roughly in the NE-SW orientation with fairly steep slopes.

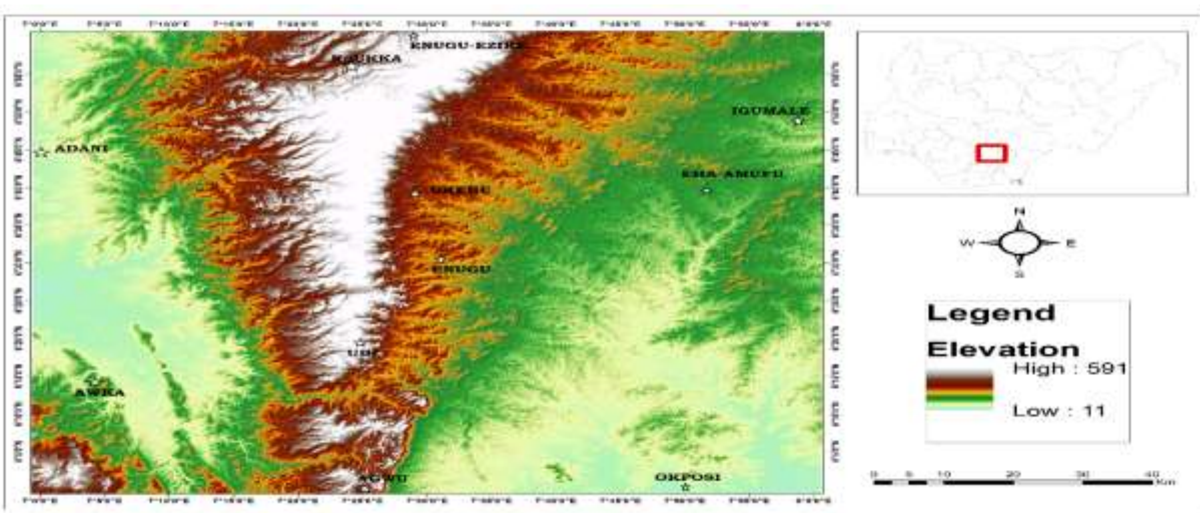

Figure 3: Elevation map of the study area

RGB Composite analysis of the elevation map was carried out for the recognition of subtle features that were ab initio not apparent in the elevation map (Figure 4). The map shows that the escarpment thickens towards the NE and thins in the SW. The escarpment is flanked by lowlands/valleys with less steep slopes and dissected with characteristic isolated hills along its axis towards the south of the study. Evidence of faulting along the escarpment to the east is also visible on the map. Result also reveal that the western part of the escarpment is steeper than the eastern part with high drainage density and vegetation index, which suggests deformation by faulting.

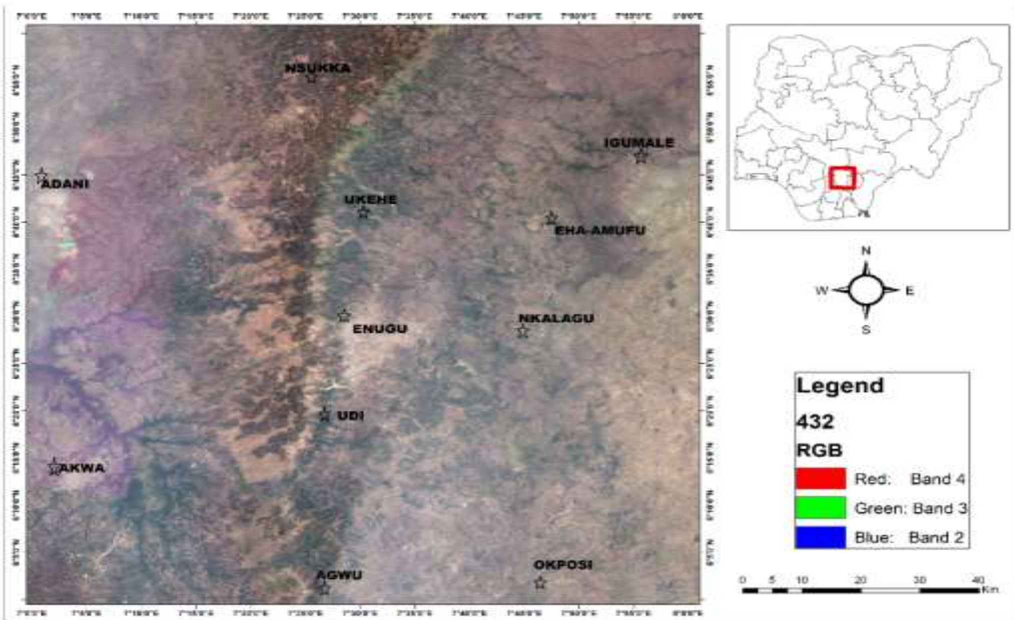

Figure 4: Composite Map of the study area.

Lineament Analysis

Lineaments are widespread and dense, occurring mostly on the escarpment (Agwu, Awka, Enugu, Nsukka, Udi, and Ukehe) and sparsely distributed in the eastern and western lowlands/valleys (Adanu, Nkalagu and Igumale). They are characterized by both short and long linears and occur in the NE-SW, NW-SE, N-S and E-W trending lineaments (Figure 5). Lineament orientation analysis using geostatical rose diagram (Figure 6), revealed that the study area is dominated mostly by monodirectional NE-SW lineament orientation, with minor occurrences of NW-SE, N-S and E-W lineament orientations.

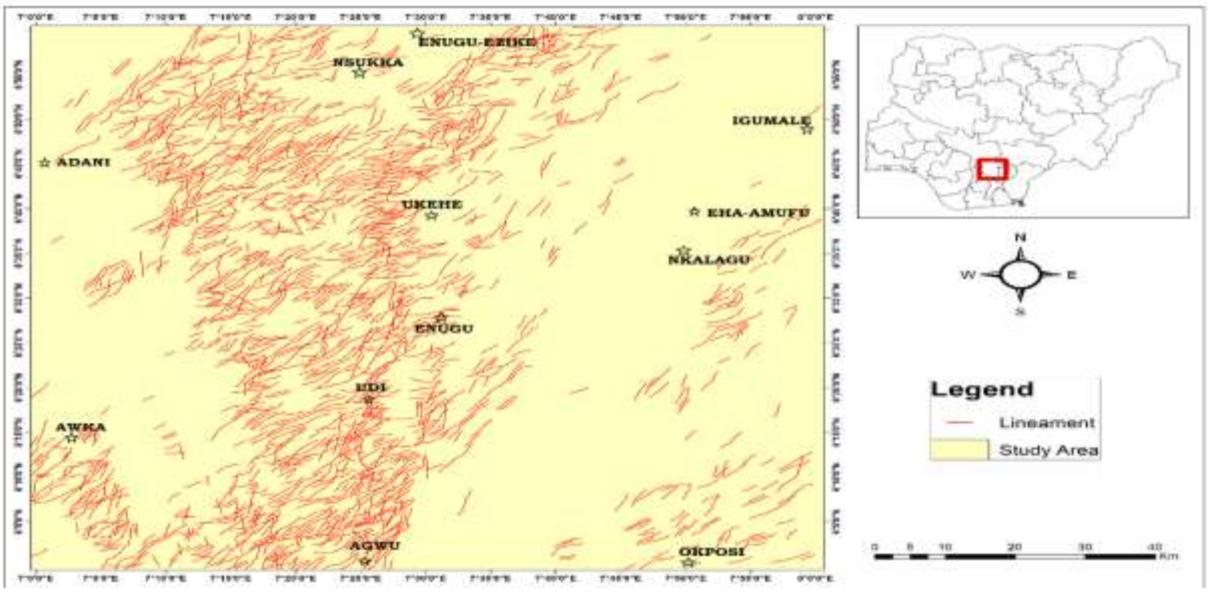

Figure 5: Lineament Map of the study area

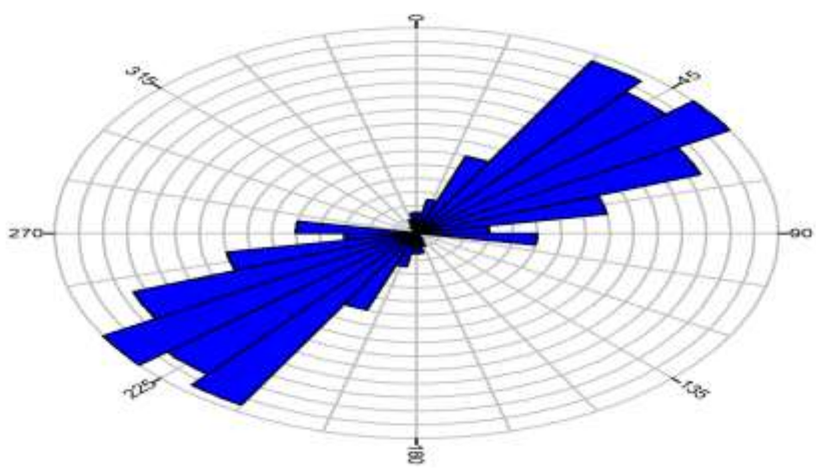

Figure 6: Rose Diagram of the study area.

The lineament density map varies from low, medium and high density (Figure 7). Agwu, Awka, Enugu, Nsukka, Udi, Ukehe areas on escarpment lie in medium to high lineament density zones, while Adanu, Nkalagu and Igumale lowland/valley areas lie in low lineament density zones. The medium to high lineament density on the escarpment indicates that it is more deformed than surrounding lowland/valley areas in the study area (Hung et al., 2002).

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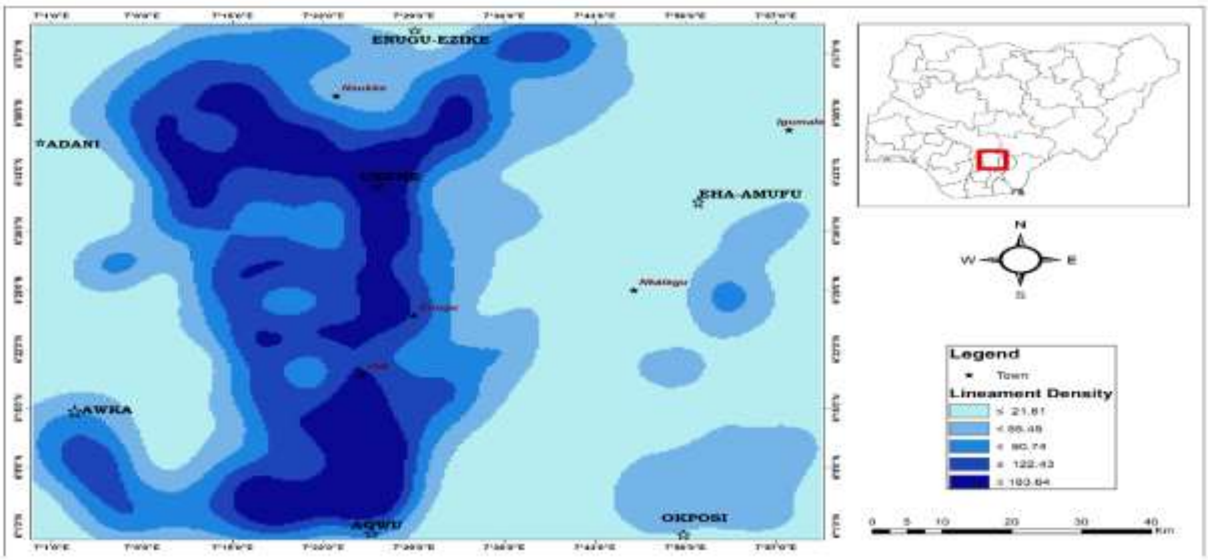

Figure 7: Lineament Density Map of the study area.

Drainage Analysis

The study area is drained by NE-SW and NW-SE bidirectional drainage network with variable texture (fine to coarse), sourced from the flanks of the escarpment in the study area. The NE-SW flowing streams dominate the western and southwestern parts and exhibit characteristic dendritic drainage pattern, while the NW-SE flowing streams occur mainly in the eastern and southeastern parts with parallel drainage pattern (Figure 8). These drainage patterns have tectonic and lithological connotations and could be related to hydrocarbon prospect zones in the basin.

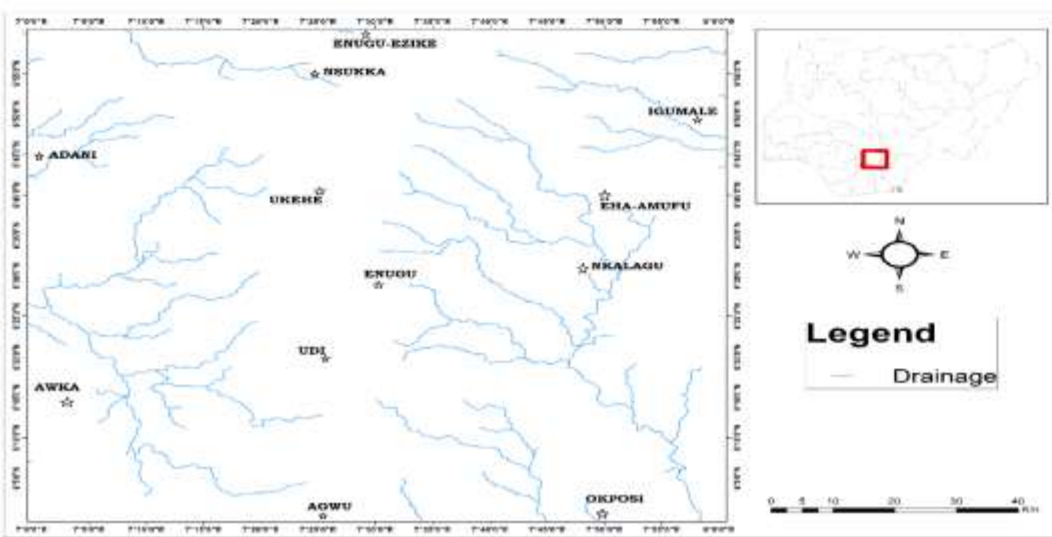

Figure 8: Drainage Map of the study area.

The drainage and lineament map overlay were generated (Figure 9), to establish relationship between lineament and drainage network in the basin. Inspection of the map indicate that the drainage network is very much similar in orientation with the lineaments mostly in the west to southwest than east to southeast of the study. This result indicate that drainage network partly conforms to structure (lineaments) and establishes a structural connection between lineaments and drainage in the basin. It also goes to show that the NE-SW oriented lineaments are sources of numerous rivers in the west and southwest of the study.

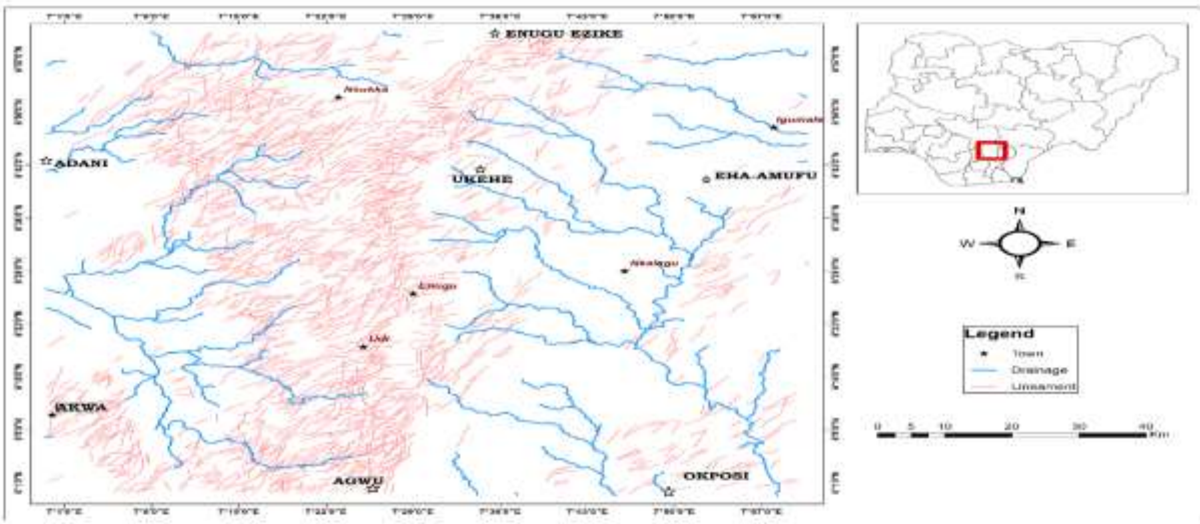

Figure 9: Lineament and Drainage map overlay

Normalized Difference Vegetation Index (NDVI**) Analysis**

NDVI values range from -0.420 to +0.602 in the study area (Figure 10), suggesting low and high vegetation index, respectively. The effect due to lineament, drainage and elevation is apparent in the form of vegetation index. Result show that the vegetation is greener along the river channels and on the escarpment, while the surrounding lowlands/valleys are less green. The high vegetation index on the escarpment and along the river channels is a manifestation of the effects due to moisture and lineaments on plants growth. The alignment of vegetation with the drainage mostly in the southwest than the southeast of the study suggests possible lithological differences as well as structural relationships.

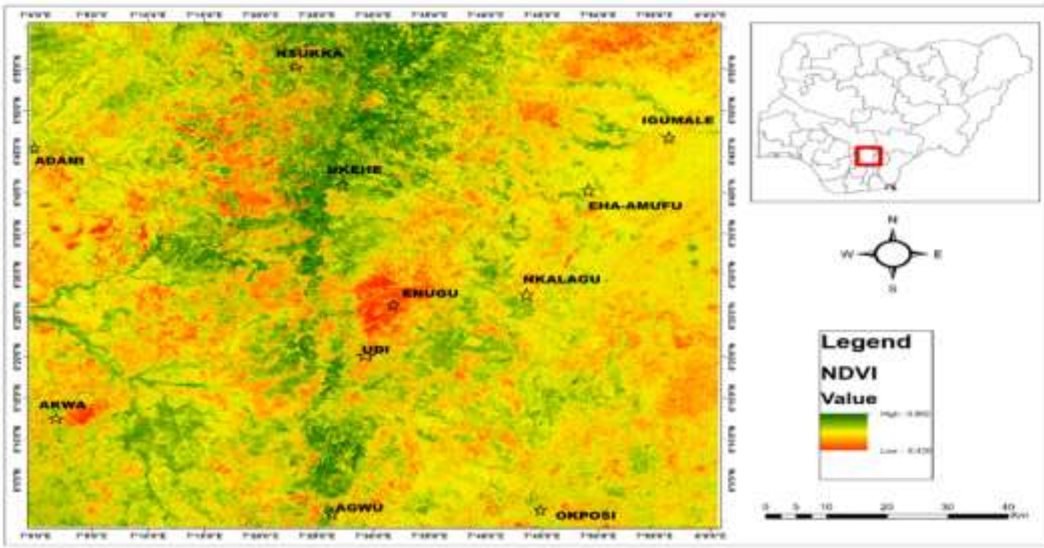

Figure 10: NDVI Map of the study area.

DISCUSSION OF RESULTS

Rifting, uplift and subsidence resulted to the development of varied geological lineaments: folds, faults, aligned hills, fracture zones, shear zones and igneous intrusions in the lower Benue basin. Lineaments play an important role in the formation of petroleum system as both gateway and barriers for migration and trapping of hydrocarbons. They are intrinsically connected to terrain attributes and partly controls they occurrence and spatial distribution in the study. In the present study, lineament analysis was carried out to evaluate lineament geometry and topology as well as establish relationships between lineaments and terrain attributes to accurately map probable hydrocarbon prospect zones in parts of the lower Benue basin.

Lineament and rose plot analysis of the study revealed widespread and dense lineament occurrence on the escarpment than the adjoining lowlands/valleys in the study area. The lineaments occur in the NE-SW, NW-SE, N-S and E-W preferred orientations. The NE-SW is the most dominant lineament orientation, while NW-SE, N-S and E-W lineament orientations are less dominant. This result is in line with the trend of the basin and agrees with the works of (Chukwu-Ike, 1977, Ananaba et al., 1987 and Udoh, 1988) in the basin. Analysis of lineament density reveal variable lineament density across the study area. Lineament density varies from low, medium to high densities. Agwu, Awka, Enugu, Nsukka, Udi and Ukehe located on the escarpment lie in medium to high lineament density, while Adanu, Nkalagu and Igumale in the lowlands/valleys lie in low lineament density.

The variability in lineament distribution patterns and lineament density across the study area may be due to rock type and degree of deformation. The rock type and prevailing tectonics determines the magnitude of rock deformation and lineament generation. According to Hung et al., (2002), high lineament density corresponds to the most deformed areas and low lineament density for less deformed areas. Therefore, the observed high lineament density on the escarpment suggests that these areas (Agwu, Awka, Enugu, Nsukka, Udi and Ukehe), are likely more deformed than surrounding lowland/valley areas (Adanu, Nkalagu and Igumale) in the study.

Terrain attributes such as drainage network, NDVI and elevation relate directly to lineaments, indicting a structural control in the study. Drainage network are similar in orientation with the lineaments and elevation in the study. Result also revealed that high drainage network corresponds to high lineament density especially, to the west and southwest of the study. The drainage channels and the escarpment are characterized by high NDVI values, indicating the importance of moisture on plant growth. The high lineament density with corresponding high NDVI value, suggests that lineaments in these areas serve as conduit through which plant roots access moisture as well as sources of numerous drainage network in the study.

Terrain attributes are generally, surface expressions of the underlying basement geology and are intrinsically connected to lineaments (Khan and Glenn, 2006 and Prabaham et al., 2012). They provide clues to the nature of the underlying geologic deformations and therefore, serve as surface geologic pointers to the identification of structurally deformed areas capable of developing petroleum entrapment structures with probable hydrocarbon prospect.

The NE-SW dominant lineament orientation and minor occurrences of NW-SE, N-S and E-W lineaments are imprints of the continental extensions of the underlying basement faults and associations, propagated into the weak overlying sedimentary strata by tectonic forces in the basin (Benkhelil, 1987, Ananaba et al., 1987, and Udoh, 1988). The connectivity and spatial relationships between these surface lineaments and their supposed basement counterparts, could provide mechanism for probable hydrocarbon migration and entrapment in the overlying sedimentary rocks.

Probable hydrocarbon prospect zones are suspected to lie in the medium to high lineament density areas, where lineament intersections and connectivity capable of trapping hydrocarbons is high. Therefore, Agwu, Awka, Enugu, Nsukka, Udi and Ukehe located on the escarpment with high lineament densities are preferred prospect areas in the study for detailed hydrocarbon exploration than Adanu, Nkalagu and Igumale areas in the lowlands/valleys with low lineament densities. According to Obaje et al., (2004), Agagu and Adighije (1983), tectonic highs (escarpments) in the lower Benue basin received comparatively thinner sediments and were even non-depositional in places, with proven potential source rock facies and the occurrence of volatile and sub-bituminous coals. They constitute favorable areas for developing petroleum entrapment structures that could be prospective zones for detailed petroleum exploration.

The result of this present study was validated by correlating lineament density and location of known hydrocarbon seepage in the study. Result revealed that high lineament density correlates with known location of hydrocarbon seepage around Egwueme in Agwu escarpment, indicating the connectivity of these lineaments with deep seated structures.

CONCLUSION

Remote sensing and GIS techniques were integrated for hydrocarbon prospect evaluation from the analysis of lineaments and terrain attributes in parts of the lower Benue basin. Lineament distribution, density and orientation vary across the study area and largely depends on the rock type and deformation. The tectonic highs (escarpment) have high prevalence of lineament density than the lowlands/valleys, suggesting a structurally deformed area. The NE-SW is the most dominant lineament orientation, while NW-SE, N-S and E-W lineament orientations are less dominant. Terrain attributes were partly lineament-controlled and lithological. They serve as geologic pointers to structurally deformed areas capable of developing petroleum entrapment structures.

Hydrocarbon prospect zones were delineated in the medium to high lineament density areas, where lineament intersections and connectivity capable of trapping hydrocarbons is high. Therefore, Agwu, Awka, Enugu, Nsukka, Udi and Ukehe located on the escarpment are preferred prospect areas in the study for detailed hydrocarbon exploration than Adanu, Nkalagu and Igumale areas in the basin. Finally, high lineament density correlates with known location of hydrocarbon seepage, indicating the connectivity of these lineaments with deep seated structures.

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