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Integrating Satellite Remote Sensing and Geographical Information System (GIS) for Hydrocarbon Exploration in Chad Sedimentary Basin

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ABSTRACT

Hydrocarbons have been a major player in growing economies and improving quality of life. In Nigeria, crude oil provides 44.1% of Nigeria's foreign export and 36.6% of its petroleum gases. The discovery of hydrocarbons in commercial quantity in the Chad Basin in north-eastern Nigeria is another milestone in improving the income of the country. However, the Chad basin exploration was concentrated only on some portion of the basin, the northern part. Previous studies provide little information on the possibility of hydrocarbon deposits in the eastern part bordering the Cameroon republic. This study integrates satellite Remote Sensing (RS) with a Geographic Information System (GIS) to analyze and have an overview of possible concentrations of hydrocarbons in the entire basin that is within the Nigerian territory. Results show that nine local government areas are liable to have a high concentration of hydrocarbon deposits at a commercial quantity. Only three local governments so far that was undergoing full exploration. This study will serve as a reconnaissance survey for NNPC and other relevant bodies in exploring the hydrocarbons in the other six local councils in Borno State Nigeria.

Keywords: Remote Sensing, Chad Basin, Hydrocarbon, Exploration,

1.0. Introduction

Hydrocarbons have been a major player in growing economies and improving quality of life (Newell and Raimi, 2018; Mayer, 2017). They provide the building blocks to create products that was used in everyday life. In Nigeria, crude oil provides 44.1% of Nigeria's foreign export and 36.6% of its petroleum gases (Statistics, 2023). Therefore, hydrocarbon resource exploration is of great importance in the nation's economy and can be explored also in states that are within the sedimentary basins.

Despite this importance, hydrocarbon exploration has been faced with many challenges. This could be environmental (Santos et al., 2018), social (Ogwang and Vanclay, 2019), and economic issues (Dudlák, 2018). The trial-by-error exploration not only wastes time but also resources. The lack of a predefined location of resources before exploration is one of the contributing factors that limit the chances of obtaining natural resources in a commercial quantity. Chad basin is one of the basins where exploration of oil and gas is going on. However, it was only concentrated on one portion of the basin.

Many studies were carried out on the exploration of the Chad basin with different techniques targeted at a specific problem. In oil and gas exploration, seismic surveys are used by many organizations to map geological structures beneath the earth's surface or beneath the seabed (Nanda, 2021; Mohammadpoor and Torabi, 2020; Xishuang et al., 2014). Reflection seismology is commonly used during the onshore exploration and involves sending seismic waves underground. Numerous studies have proved the connection between low-amplitude local anomalies of *gravity* and magnetic field with *oil and gas deposits (*Liu et al., 2022; Al-Farhan et al., 2019; Hinze et al., 2013). These studies were used to identify the nature and depth of the magnetic sources that will interpret the main subsurface structures such as hydrocarbon deposits (de Smet et al., 2021; Nikulin and de Smet, 2019). Very few studies were conducted on the use of digital elevation models and surface lithology to predict the possible deposit of hydrocarbons. In most research, elevation models for hydrocarbons exploration were primarily used for well drilling and seismic attributes (Zhang et al.,2022; Djezzar et al., 2022); whereas surface lithology was mainly used to detect the hydrocarbon seepage (El-Hadidy et al., 2022; Cvetković, et al., 2021; Lord, 2017).

This study uses satellite RS and GIS and produced a predictive hydrocarbon resource map. Remote sensing and GIS were integrated and used for specific geological data classes. Satellite RS techniques cover a wider area of coverage for hydrocarbon exploration and give a precise location of predictive areas using certain parameters such as elevation and lithology. This technique is faster and less costly, unlike other techniques. It involves the use of field and laboratory spectral data in organizing remote sensing products. With multispectral scanners from orbiting satellites, our study used an elevation model and lithological map to identify the possible location of hydrocarbons within the Chad basin in Nigeria. The result of the work may be useful for NNPC and other stakeholders in the oil and gas sector as a reconnaissance survey.

2.0. Methodology

2.1. Study Area

The study area is Chad sedimentary basin in Northeast Nigeria (Figure 1.) The Chad Basin is the largest endorheic basin in Africa, centered on Lake Chad. It has no outlet to the sea and contains large areas of semi-arid desert and savanna. The area under investigation in this study is the Chad basin within the territory of Nigeria. The estimated area from the software we used was 7,866,795 hectares.

Figure 1. Chad Sedimentary Basin

2.2. Materials

The materials used in this work *were* digital elevation model that describes the surface elevation of bare earth of the study area and the lithology map of the area concerned. A digital elevation model at a good resolution can be used for the detection of subtle, positive geomorphic anomalies related to hydrocarbon microseepage (vertical migration) on possible oil and gas targets (Pardo Echarte et al., 2018; Echarte et al., 2018). The identification of a surface lithology is fundamental to all reservoir characterization because the physical and chemical properties of the rock or soil that holds hydrocarbons influence the reflectance values that can lead to the possible detection of hydrocarbon locations.

2.3. Methods

This method was in three categories: (a) Satellite data collection, (b) Data analysis, and (c) presentation of the information as a map showing the possible location of hydrocarbon deposits in the study area.

2.3.1 Data Collection

Two sets of data were collected. These were the Landsat 8 Operational Land Imager (OLI) satellite data and the Shuttle Radar Topography Mission (SRTM). Six Landsat 8 OLI satellite images were collected altogether. The file id, number of bands used, and the acquisition date of the Landsat images were presented in Table 1. They were used to derive the surface lithology of the study area. In order to understand the nature and distribution of subsurface deposits, surface lithology is a reflection to some extent of the subsurface.

Table 1. Landsat 8 OLI image data.

s/n	Image Id	Bands	Acquisition date
1	LC08_L2SP_186051_20220428_20220503	2,3,4	28th April 2022
2	LC08_L2SP_186052_20220428_20220503	2,3,4	28th April 2022
3	LC09_L2SP_185051_20220429_20220501	2,3,4	29th April 2022
4	LC09_L2SP_187051_20220427_20220429	2,3,4	27th April 2022
5	LC09_L2SP_187052_20220427_20220429	2,3,4	27th April 2022
6	LC09_L2SP_185052_20220429_20220501	2,3,4	29th April 2022

The elevation data collected is the Shuttle Radar Topography Mission (SRTM). It uses radar signals to collect the elevation of predefined points at 30m intervals. It was accessed online via earth explorer. The elevations are arranged in tiles where each tile covers one degree of latitude and longitude, which was named accordingly from their southwestern corners.

2.3.2 *Data Analysis*

Image mosaicking is an effective means of constructing a single seamless image by aligning multiple partially overlapped images. Image-mosaicking algorithms are used to get mosaiced images. several arbitrarily shaped images were formed as one large radiometrically balanced image whereby the boundaries between the original images are not seen. Using the algorithms within ArcMap 10.3, six images of bands 2, 3, and 4 were mosaic together to cover the study area.

The chemical alterations associated with ancient hydrocarbon seeps can be detected in these rocks by multispectral remote sensing methods. This is possible when you use lithological operations that can display possible surface reflectance. The display of surface lithology must do the combination of some spectral bands that will portray the natural surface as it exists. This is known as color composite imaging and is displayed in three primary colors (red, green, and blue). In Landsat imagery, the combination bands 2, 3, and 4 will give the color composite of the study area. To extract the surface lithology, supervised classification techniques were performed. Areas with a higher lithologic reflectance were selected as training cells.

The elevation model of the basin was derived from SRTM data. The elevation data were classified into five classes. An elevation lower than 320m above the mean sea level (MSL) was considered a possible location for hydrocarbon deposits. An intersection lithologic map with the elevation model gives the hydrocarbon predictive map of the basin.

2.3.3 *Presentation of the Information*

Three maps were presented altogether. Lithological map, elevation map, and the final map showing areas that need to be explored for hydrocarbon deposits. The results of the analyzed data were presented as a map showing locations of possible deposits of oil and gas that was yet to be explored.

3.0. Results and Discussion

3.1. Results

3.1.1 Lithology Map

The creation of a lithology map yields valuable insights into the formation and possible location of hydrocarbon deposits in the Chad basin. The brown colour represents the possible location of hydrocarbon deposits. The map was presented in Figure 2.

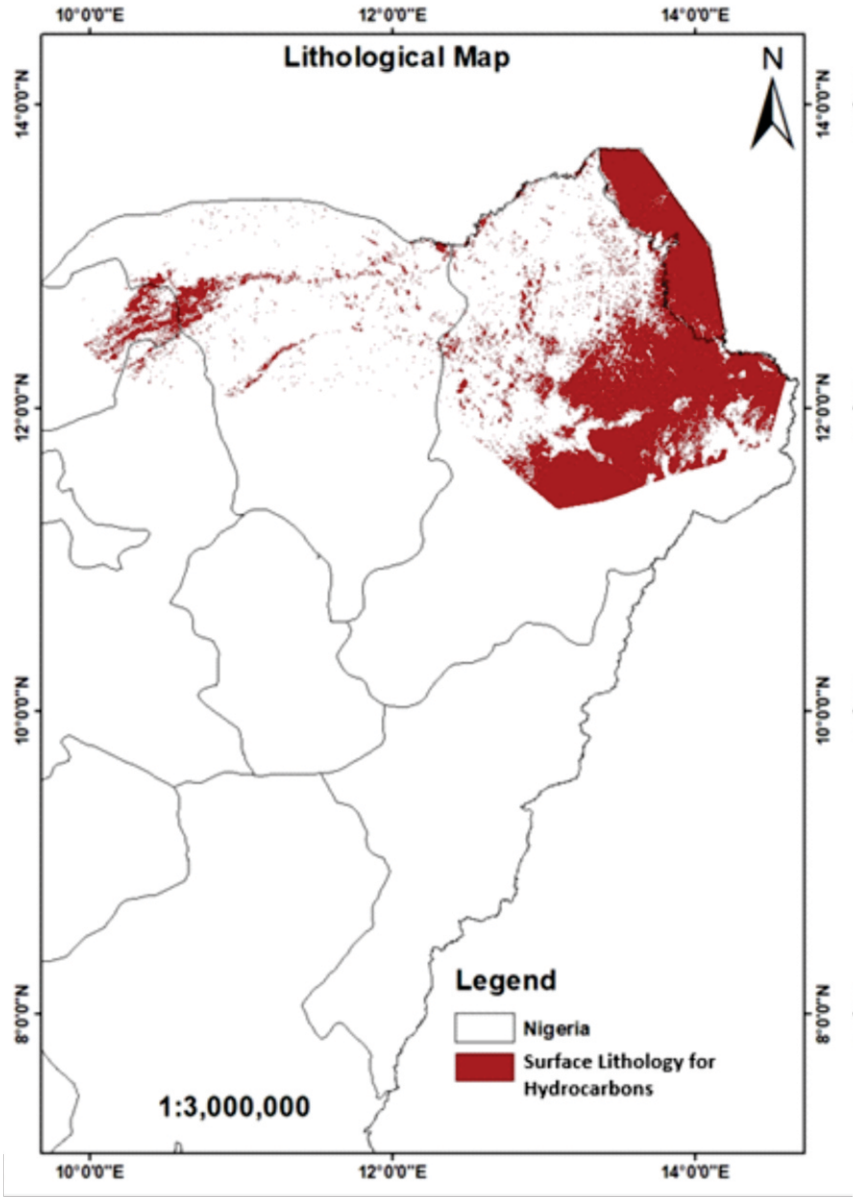

Figure 2. Surface lithology of Chad Basin

From the figure above, it can be seen that there is more surface reflectance value in the north eastern part of Borno state. Very little reflectance within the northern part of the Yobe and Jigawa states.

3.1.2 Elevation Map

Migration is an important step in seismic data processing for oil and gas exploration. The accuracy of migration directly affects the accuracy of subsequent oil and gas reservoir characterization. Thus, surface elevation influences the migration of subsurface materials in form of liquid or wax deposits. The result of the elevation model in five classes was presented in Figure 3.

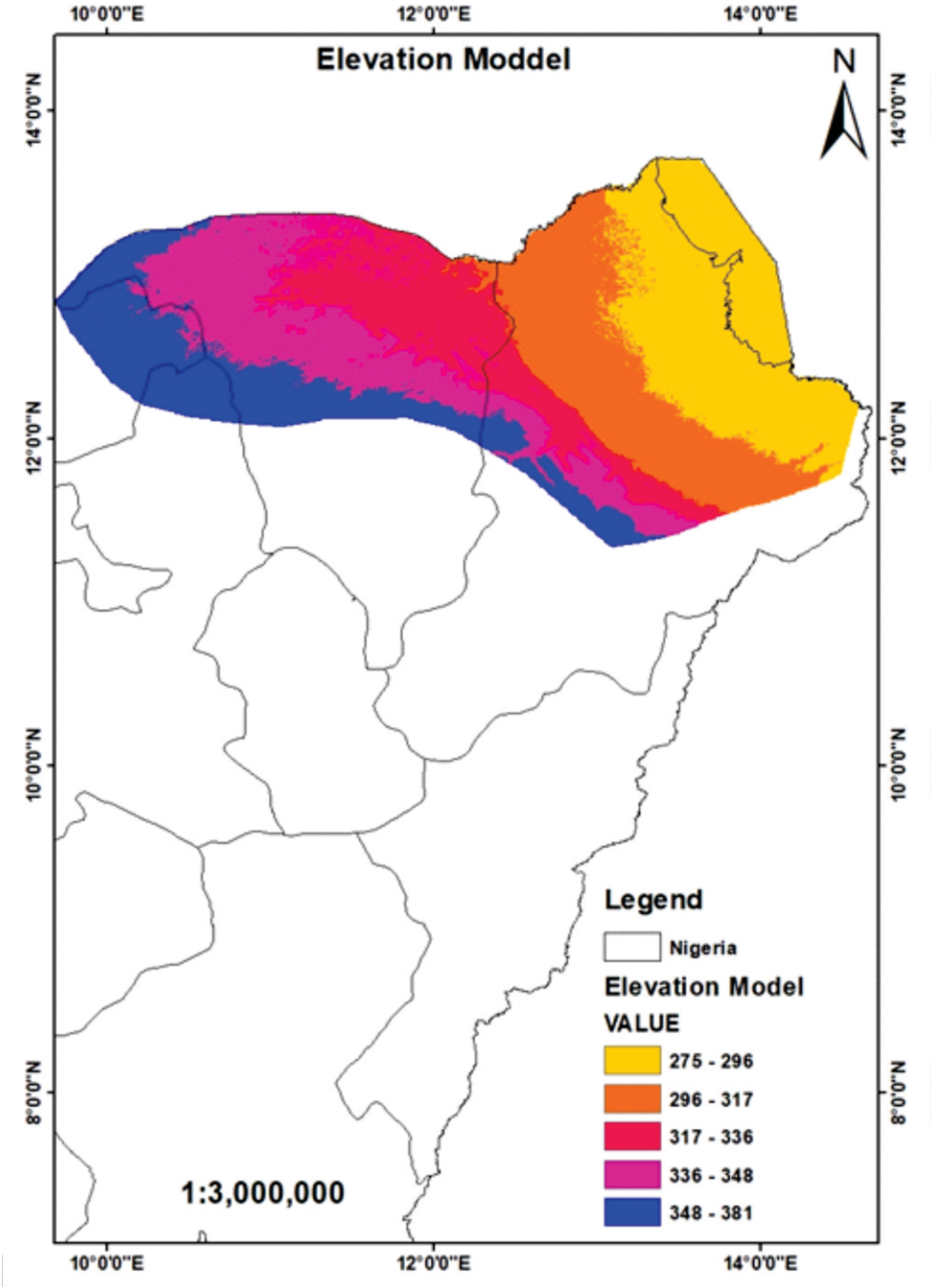

Figure 3. Elevation model of Chad Basin

The elevation ranges from 381 as highest and 275m as the least. It was expected that elevations from 275m to 317m may have possible deposits of migrated materials since they are the lowest elevation in the basin.

3.1.3 Hydrocarbons Resource Map

The analysis of the lithological and elevation model of the basin reveals a versed area that indicates the deposit of hydrocarbon materials. It is more pronounced in the northeast part of Borno towards the Cameroon republic (Figure 4).

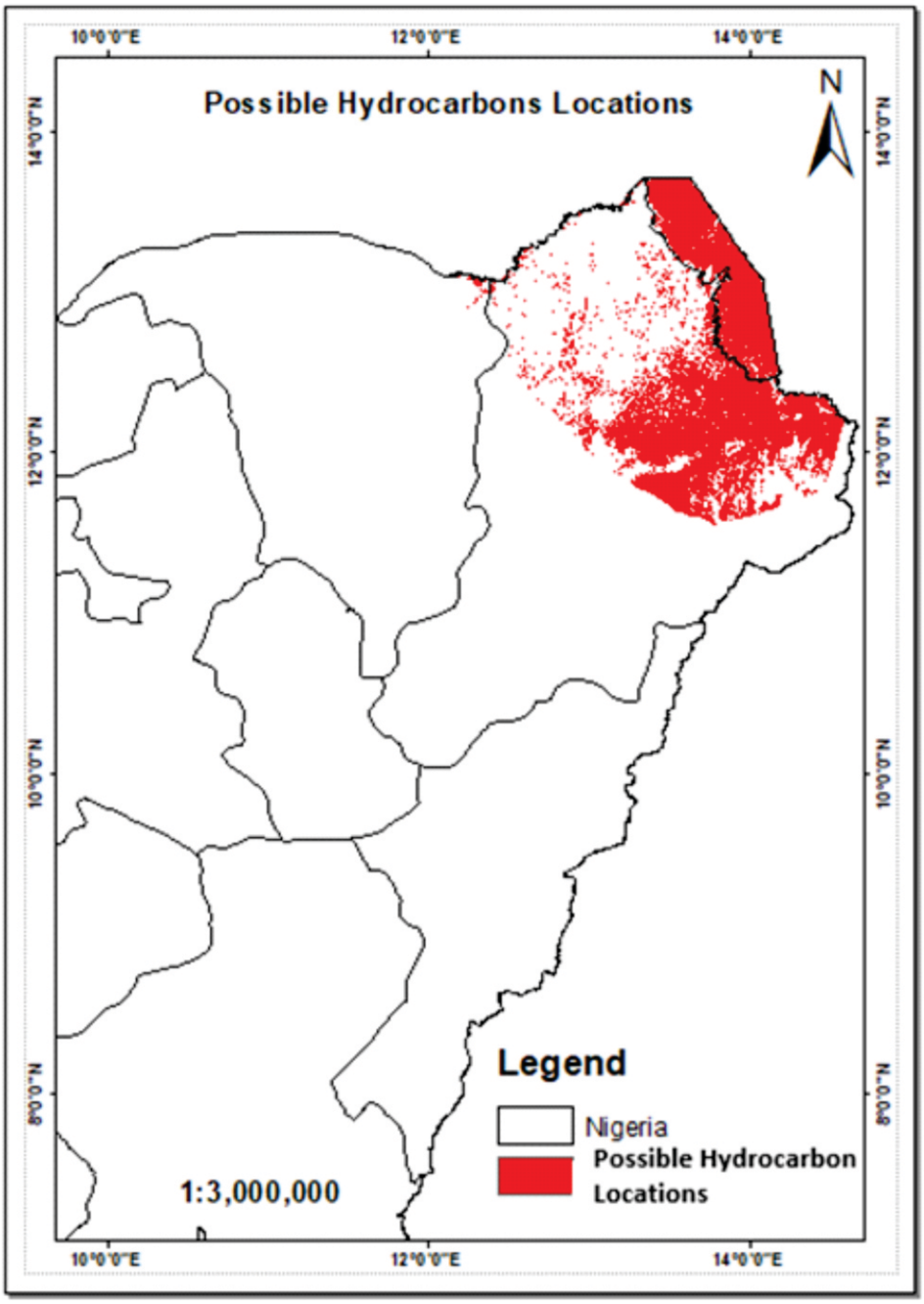

Figure 4. Hydrocarbon resource map

The result in Figure 4 indicate the possible occurrences of hydrocarbon deposits were more in the northeastern part of Borno state bordering Cameroon than in the northern part bordering Chad republic. Nine local councils were among the areas with high deposits of hydrocarbon (Figure 5).

3.2. Discussion

Hydrocarbon exploration of the Chad Basin within the Nigerian territory was carried out by the Nigerian National Petroleum Investment Management Services (NAPIMS) of the Nigerian National Petroleum Corporation (NNPC). Most parts of the basin remain underexplored for hydrocarbon deposits. Most concentration by NNPC is within Abadam, Mongono, and Kukawa Local Councils of Borno state. However, Marte, Ngala, Mafa, Dikwa, Kala Balge, and Bama also has a higher probability of hydrocarbon concentration (Figure 5).

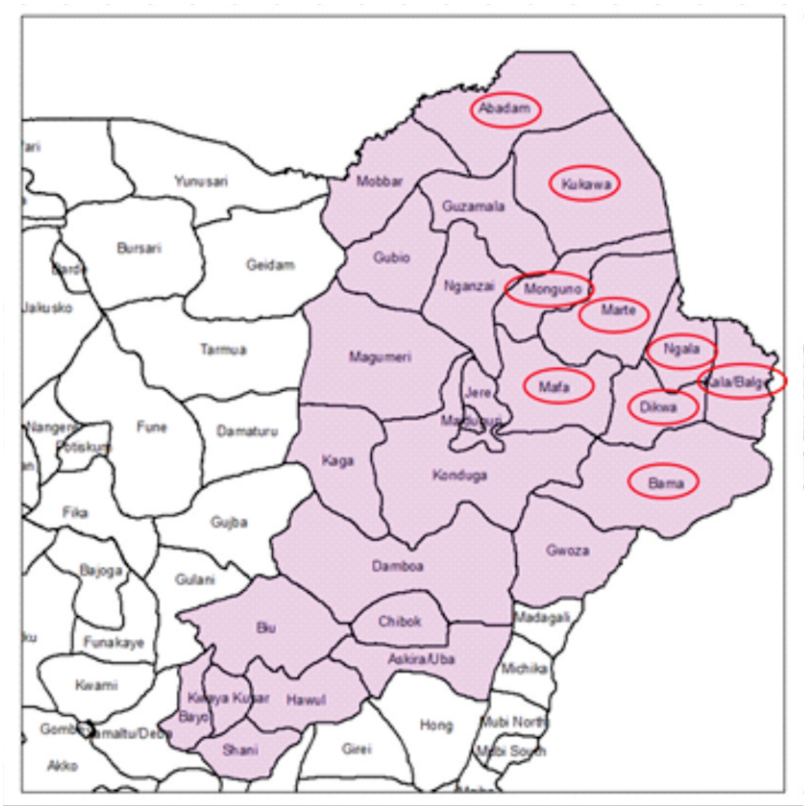

Figure 5. Map of Borno state showing local councils with hydrocarbon potentials.

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Since the discovery of Hydrocarbons in the sedimentary basins of the East Niger Graben that was structurally controlled by the major rift systems influencing Benue, Chad, Sudan, and Libya, there is a quest for full exploration of the entire basin and more specifically in the eastern part that remains unexplored.

Exploration of Hydrocarbon has numerous challenges, particularly in Chad sedimentary basin. It is too difficult, too expensive, and too politically unstable to justify operations. Therefore, the use of a predictive map such as the one in this work will help the exploration activities within a limited time and at a lesser cost.

4.0. Conclusions

RS and GIS were integrated to get areas in Borno state that has a high possibility of hydrocarbon deposits but were yet to be explored. Local councils of Bama, Dikwa, Mafa, Kala Balge Ngala, and Marte show a high level of hydrocarbon deposits through the analysis of the surface reflectance and elevation model. The result of this study will be useful to NNPC and other stakeholders in the oil and gas sector.

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