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Use of Remote Sensing and Geographic Information System in Accessing the Spatial Distribution of Bitumen in Dahomey Sub-Basin, Southwestern Nigeria

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***Abstract**: Bitumen is a mixture of organic liquids that are highly viscous, black, sticky and entirely soluble in carbon disulphides which are properties that could be captured using Remote Sensing and Geographic Information System. Bitumen outcrops in several places along bitumen belt of Dahomey basin, south Western Nigeria. The outcrop verification of the bitumen was carried out in Ilubirin, Agbabu and Ode-Irele in South-western Nigeria to determine their spectral characteristics with a view to using them to draw inferences in other areas where bitumen outcrops within the belt. The ground verification points were processed using remotesensing and Geographic Information System (GIS).The results obtained from the analysis shows that bitumen outcrops in Ilubinrin, Agbabu and Ode-Irele have high surface temperature, high surface albedo, low surface emissivity, low leaf area index and low normalized difference vegetation index. The spectral characteristics of the satellite of the known bitumen outcrops were used to locate the unknown bitumen outcrops in the study areas. This study has shown that geospatial tools such as the GPS (Global Positioning System), GIS and remote sensing could be used for bitumen exploration*.
Keywords: Remote Sensing, Geographic Information System, spatial distribution, Spectral indices, Bitumen

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I. Introduction

Tar sand is composed of sand, heavy oil and clays that are rich in minerals and water. The heavy oil in tar sand is called bitumen. Bitumen is a naturally occurring, complex viscous mixture of hydrocarbons. It is the heaviest, thickest form of petroleum. In its natural state, it is not recoverable like conventional petroleum through wells but may be refined into petroleum products such as gasoline, kerosene, or gas oil without first being upgraded to crude oil (Akinmosin et al., 2009). Bitumen has similar composition as the light crude i.e. hydrogen, carbon and minor amount of sulfur and oxygen. Bitumen is believed to have been formed from biodegrading and water washing of light crude. The Nigerian bitumen is believed to have formed in a similar process (Akinmosin et al., 2009). Prospecting for oil and bitumen in Nigeria started long before the birth of Nigeria as a political entity as we know it today (Onoh 1983, Nwaochei 1986 and NNPC, 1990). According to Onoh (1983), a German company started exploration for bitumen in 1908 along the coastal region stretching from Okitipupa in Ondo State to Lagos. The first discovery of hydrocarbon in 1909 was on the tar sand belt in the coastal area of the Western part of the country (Eke, 2004). Although very heavy crude oil was produced from wells sunk on the deposit, the discovery of light to medium oil in commercial quantity started at Oloibiri in the Niger Delta area in 1956 by Shell BP, a company formed in 1946 by Shell D'Arcy which started exploration in 1937 in partnership with British Petroleum and this led to the abandonment of the exploration of the bitumen sands (NNPC, 1990, Eke, 1995). Previous localities studied include Idiobiolayo (Akinmosin and Shoyemi, 2010), Agbabu (Amigun et al., 2012), Imeri (Akinmosin et al., 2011), Idiopopo (Odunaike et al., 2010), Onikitibi (Akinmosin et al., 2012), and Imobi (Ikhane et al., 2011). These works used sedimentological and geophysical methods to characterize the bitumen and its host units.Satellite remote sensing is an important data source for monitoring, detection, quantification, and mapping of land cover patterns and changes, because of its large spatial coverage, repetitive data acquisition, digital format appropriate for computer processing, and accurate geo-referencing approaches (Jennings 2000; Kerr and Ostrovsky 2003; Rogan and Miller 2006; Pellikka et al. 2009; Loveland and Dwyer 2012). The advent of geographic information system (GIS) has also made it possible to integrate multisource and multitemporal data for the generation of changes in land surface components involving such information as the trend, rate, nature, location and magnitude of the changes (Adeniyi and Omojola 1999). Yue et al. (2007) and Wei et al. (2008) employed the Greenness Vegetation Index (GVI), Soil Adjusted Vegetation Index (SAVI), Normalized Difference Vegetation Index (NDVI), Ratio Vegetation Index (RVI) and the Normalized Difference Built-up Index (NDBI) to estimate the relationship between land surface temperature and vegetation. Adeyeri et al. (2017) investigated urban heat island over Abuja based on the relationship between land surface temperature estimated from Landsat 8 Thermal Infrared Sensor (TIRS) band and four vegetation indices from Landsat 8 Operational Land Imager (OLI) bands. The result shows that the Land Surface Temperature, hot spots and cold spots have been greatly influenced by the Land use Land cover of the area. Therefore, this work seeks to demonstrate the usefulness of GIS in conjunction with Remote Sensing in determining the spatial distribution of bitumen in the bitumen belt of the South Western Nigeria.

II. Study Location And Site Description

2.1 Study Location:

The study area falls between Latitudes 6^0 35'N and 6^0 39'N and Longitudes 4^0 48' E and 4^0 54' E (Fig 1). It is an area of lowlands with few ridges, about the lowlands; the hills are very high which are characteristic of the tropical rainforest of Southwestern Nigeria. The study area has a tropical climate. There are two distinct seasons, the wet season and the dry season. Wet season normally lasts from April to October while the dry season lasts from November and ends in March. Rainfall varies from 1,900 mm to 2,700 mm annually with temperature ranging between 21.4^0 and 31.1^0C and its mean annual relative humidity is about 77.1% (Iloeje, 1978).The village has nucleated settlements with people whose occupations are mainly trading and peasant farming. During hot weather, the bitumen melts and stains the water which the local people use for their drinking and domestic purposes (Obasi, 2016).The Nigerian bitumen belt lies on the onshore areas of the eastern Dahomey (Benin) Basin, within Longitudes $3^0$45'E and $5^0$45'E and Latitudes $6^0$00'N and $7^0$00'N. The belt is about 120km long and spans from Lagos State to Siluko in Edo State and Akotogbo in Ondo State (Adegoke et al., 1981). The main bitumen belt in Nigeria occurs on the eastern margin of a coastal sedimentary basin known as the Benin Basin, which extends through Togo and Benin Republic to Western Nigeria. The crystalline basement rocks form the foundation of the whole area (Sheikh, 2003; FMSMD, 2006).

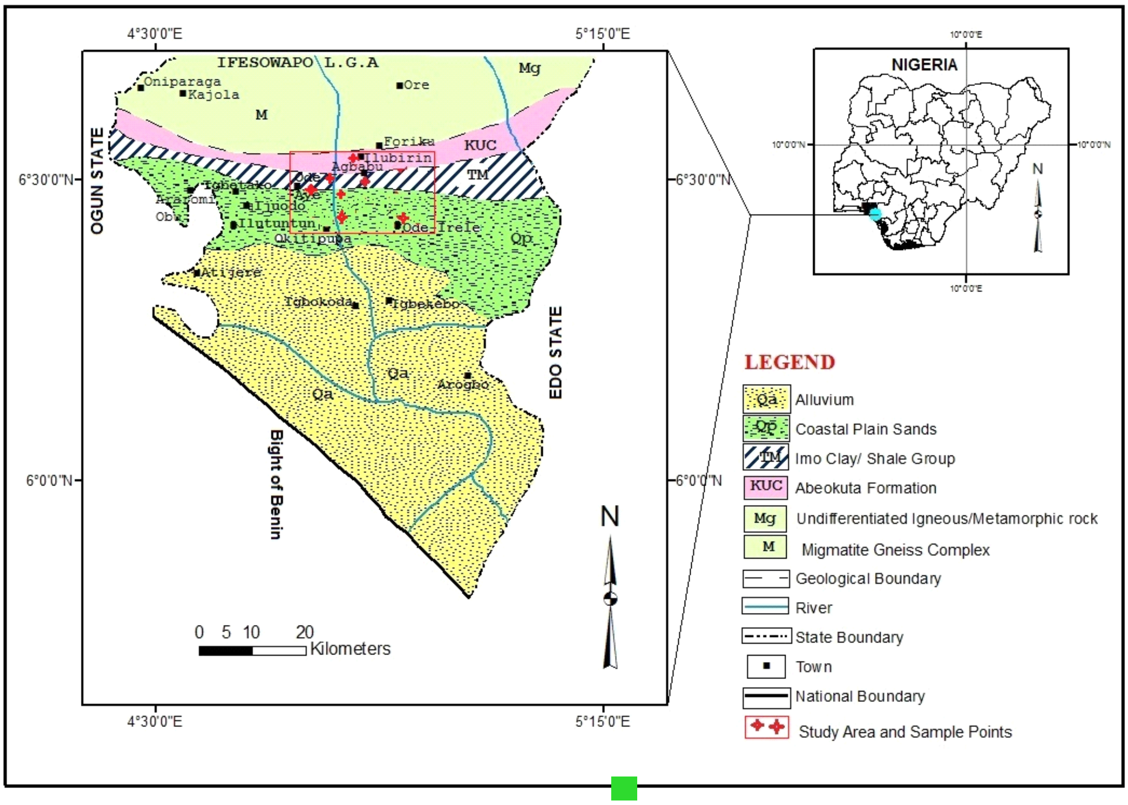

Fig 1: Geological Map of Southern part of Ondo State showing the Study Area (Obasi et al., 2016).

2.2 Geological Setting of the Study Area:

The study area lies within the Dahomey Basin. The basin is generally long with a total length of about 800 km, narrow and parallel to the coastline. It extends from southeastern Ghana to the western flank of the Niger Delta. The Dahomey Basin is a peri-cratonic basin that developed during the initiation of rifting associated with the opening of the Gulf of Guinea in early Cretaceous (Burke et al., 1971; Klemme, 1975; Whiteman, 1982; Kingston et al., 1983). The crustal separation and thinning of the basin was accompanied by an extended period of thermal-induced basin subsidence through the mid Cretaceous to Tertiary times as the South American and the African plates entered a drift phase to accommodate the emerging Atlantic Ocean (Storey, 1995 Mpanda, 1997).Dahomey basin contains extensive wedge of Cretaceous to recent sediments, which thicken towards the offshore. Six lithostratigraphic units (Fig 2) have been identified by Omatsola and Adegoke (1981). The formation from the oldest to the youngest includes: Abeokuta group (Cretaceous), Ewekoro Formation (Paleocene), Akinbo Formation (Paleocene-Eocene), Oshosun Formation (Eocene), Ilaro Formation (Eocene) and Benin Formation (Oligocene-Recent).

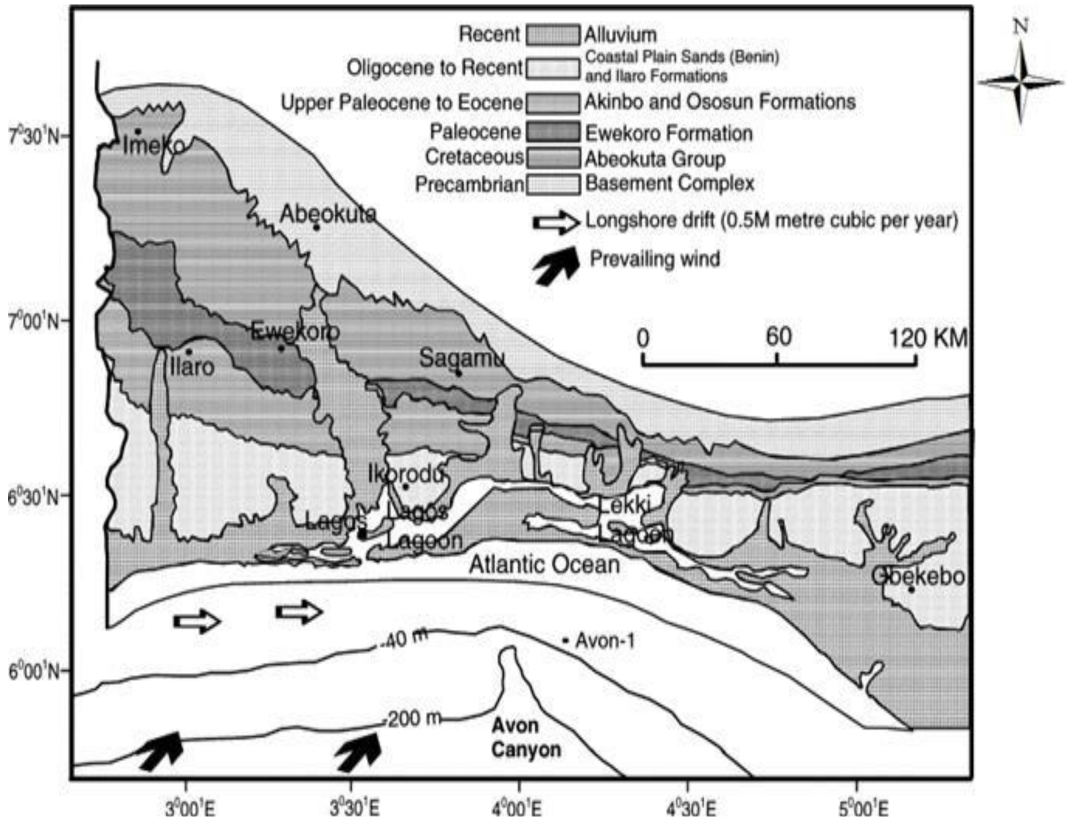

Fig 2: Outline geological map of Dahomey Basin (west of the Niger Delta). Map modified after Adekeye et al. (2006)

III. Data And Methodology

3.1 Data:

Ground verification points of the bitumen were acquired at Agbabu,Ilubinrin, and Ode-Irele, Southwestern Nigeria using (GPS). Landsat 7 / Enhanced Thematic Mapper satellite of Path 190 and Row 55 was acquired from the United States Geological Survey (USGS) and used to calculate the Reflectance and Vegetation parameters. Landsat dataset has proven useful in monitoring environmental and climate issues (Alavipanah et. al, 2010; Narayan et. al, 2016; Mfondoum et. al, 2016). Landsat 7 bands 6.1 and 6.2 are the thermal bands.

3.2 Methodology:

The basic processing structure include: Conversion to Spectral Radiance, Conversion to Spectral Reflectance, determination of the top of the atmosphere albedo, determination of the surface albedo, determination of Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI) and Leaf Area Index (LAI), determination of Emissivity, determination of brightness temperature and determination of the surface temperature.

IV. Computational method

The spectral radiance rescaling values was computed using the metadata file of each image. It was calculated using the algorithm below (Ralf et al. 2002):

$$\text{Radiance} = \frac{(L_{MAX} - L_{MIN})}{(Q_{CALMAX} - Q_{CALMIN})} \times (Q_{CALMAX} - Q_{CALMIN}) + L_{MIN} \quad (1)$$

Where $\mathbf{L_{MAX}}$ is Spectral Radiance Range or high gain for specific band at digital numbers 0 or 1 and 255, $\mathbf{L_{MIN}}$ is Spectral Radiance Range or low gain for specific band at digital numbers 0 or 1 and 255, $\mathbf{Q_{CALMIN}}$ is the value, which can be the lowest among Digital numbers, $\mathbf{Q_{CALMAX}}$ is the value, which can be the highest among Digital numbers, $\mathbf{Q_{CAL}}$ is Digital Numbers.

The spectral radiance retrieved from each Landsat imagery was converted to planetary reflectance or albedo using equation 2 Markham and Barker (1987) and NASA (2002):

$$\rho_\lambda = \frac{\pi . L_\lambda . d^2}{ESUN_\lambda \ COS\theta} \quad (2)$$

ρ_λ = planetary reflectance; L_λ is the at-satellite spectral radiance [Wm^{-2} $ster^{-1}$ μm^{-1}], which is the outgoing radiation energy of the band observed at the top of atmosphere by the satellite, d is the normalized Earth-Sun distance, Cos θ is the cosine of the solar incident angle, and $ESUN_\lambda$ is mean solar irradiances [Wm^{-2} $ster^{-1}$ μm^{-1}] for each band λ.

The proportion of incident light reflected by the top of the atmosphere is calculated using equation 3:

$$\alpha_{toa} = W_{\lambda i} \rho_{\lambda i} \quad (3)$$

Where α_{toa} = albedo of the top of the atmosphere, $W_{\lambda i}$ = weighting coefficient of each band, $\rho_{\lambda i}$ spectral reflectance corresponding to each band.

The surface albedo is the proportion of the incident light reflected by the surface and is obtained from the albedo of the top of the atmosphere (α_{toa}) using equation 4 (Menenti et al., 1989):

$$T_{sw} = 0.75 + 2.10^{-5} \times Z$$

$$\alpha = \frac{\alpha_{toa} - \alpha_{path\_radiance}}{T_{sw}^2} \quad (4)$$

Where T_{sw} is the shortwave atmospheric transmittance, α is the surface albedo, Z is the elevation above sea level (m), α_{toa} is the top of the atmosphere albedo, $\alpha_{path\_radiance}$ is the albedo path radiance.

The spectral indices, normalized difference vegetation index (NDVI), Soil adjusted vegetation index (SAVI) and leaf area index (LAI) were used to characterize the land cover types. The NDVI is a sensitive indicator of the amount and condition of green vegetation (Ishola et al., 2016). Values for NDVI range between −1 and +1. The NDVI normalizes green leaf scattering in the near infrared wavelength and chlorophyll absorption in the red wavelength (Jensen 2000). SAVI is an index that attempts to “subtract” the effects of background soil from NDVI so that impacts of soil wetness are reduced in the index. The LAI is the ratio of the total area of all leaves on a plant to the ground area represented by the plant. It is an indicator of biomass and canopy resistance (Ishola et al., 2016). The NDVI is computed using equation 5.

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}} \quad (5)$$

Where ρ_{NIR} is near-infrared reflectance and ρ_{red} is the reflectance in the red region of the visible spectrum, near –ve indicates built up areas, –ve indicates water bodies, +ve indicates thick vegetation.

$$SAVI = (1 + L)(\rho_4 - \rho_3)/(L + \rho_4 + \rho_3) \quad (6)$$

where L is a constant for SAVI. If L is zero, SAVI becomes equal to NDVI. A value of 0.5 frequently appears in the literature for L. However, a value of 0.1 is used. The value for L can be derived from analysis of multiple images where vegetation does not change, but surface soil moisture does.

$$LAI = -\frac{In\left(\frac{0.69 - SAVI}{0.59}\right)}{0.91} \quad (7)$$

Emissivity is the emitting ability of the bitumen compared to that black body. Surface emissivity is estimated using NDVI and an empirically-derived method (Bastiaanssen et al., 1998a):

Emissivity= 1.009 ×0.47 In(NDVI) (8)

Where NDVI= Normalized Difference Vegetation Index

Brightness temperature is the temperature of a blackbody that when placed in front of the detector will produce the same received flux in the spectral band as that observed. This is calculated using equation 9

$$T_b = \frac{K_2}{In\left(\frac{K_1}{L_6} + 1\right)} \quad (9)$$

Where L_6 is the spectral radiance of thermal band 10 [$Wm^{-2}sr^{-1}\mu m^{-1}$], T_b is the brightness temperature, K_2 and K_1 are found in the meta-data file (satellite property), K_1 = 666.09, K_2 = 1282.71

Surface temperature was calculated using equation 10:

$$T_S = \frac{T_b}{E_O{}^{0.25}} \quad (10)$$

Where T_S =surface temperature, T_b= brightness temperature, E_0 = emissivity

V. Results And Discussion

Most of the bitumen outcrops found in almost all the locations were under water (figure 2) which correlates to the study areas having low Leaf Area Index and low Normalized Difference Vegetation Index i.e. light vegetation. The summary of the spectral characteristics of the bitumen of the area of study is shown in Table 1.


Fig. 2: Exposures of the bitumen at the study areas. In hand specimen, the bitumen is wet, very fine and sticky

TABLE 1: Summary of the Spectral Characteristics of the bitumen for the area of study

SPECTRAL CHARACTERISTICS	VALUES
Surface emissivity	0.95-0.97
Surface temperature	31-44
Leaf area index (LAI)	0.15-0.93
Normalized difference vegetation (NDVI)	0.20-0.51
Surface Albedo	0.16-0.37
Bitumen threshold	1

4.1 Spectral Characteristics.

Surface emissivity:

Surface emissivity is the emitting ability of the bitumen compared to that of black body and its spectral property varies with composition of the material and the geometric configuration of the surface. In Figure 3, the surface emissivity value ranges from 0.95-0.97 which suggests that bitumen found in the area has a low surface emissivity.

Surface temperature:

Surface temperature is the temperature of the body or surface and is a measure of the amount of heat energy contained in it. In Figure 4, the surface temperature value ranges from 31-44^{0}C which suggests that bitumen found in the area has a high surface temperature. There is an inverse relationship between surface temperature and emissivity i.e. areas of high emissivity will have low surface temperature and areas of high surface temperature will have low emissivity.

Leaf area index:

Leaf Area Index is a dimensionless quantity that characterizes plant canopies. It is defined as one-sided green leaf area per unit ground surface area. It characterizes the canopy-atmosphere interface where most of the energy fluxes are exchanged. In Figure 5, the Leaf Area Index value ranges from 0.15-0.93 suggesting that bitumen found in the area has a low leaf area index.

Normalized difference vegetation index:

Normalized Difference Vegetation Index (NDVI) is a simple, but effective vegetation index for quantifying green vegetation. In Figure 6, the NDVI value ranges from 0.20-0.51suggesting that the known bitumen points of the area of study have a low NDVI from which it can be deduced that the study area has light vegetation and constitutes more of water bodies.

There is a direct relationship between the Leaf Area Index and Normalized Difference Vegetation Index i.e. areas of high Leaf Area Index will have high Normalized Difference Vegetation Index and areas of low Leaf Area Index will have low Normalized Difference Vegetation Index.

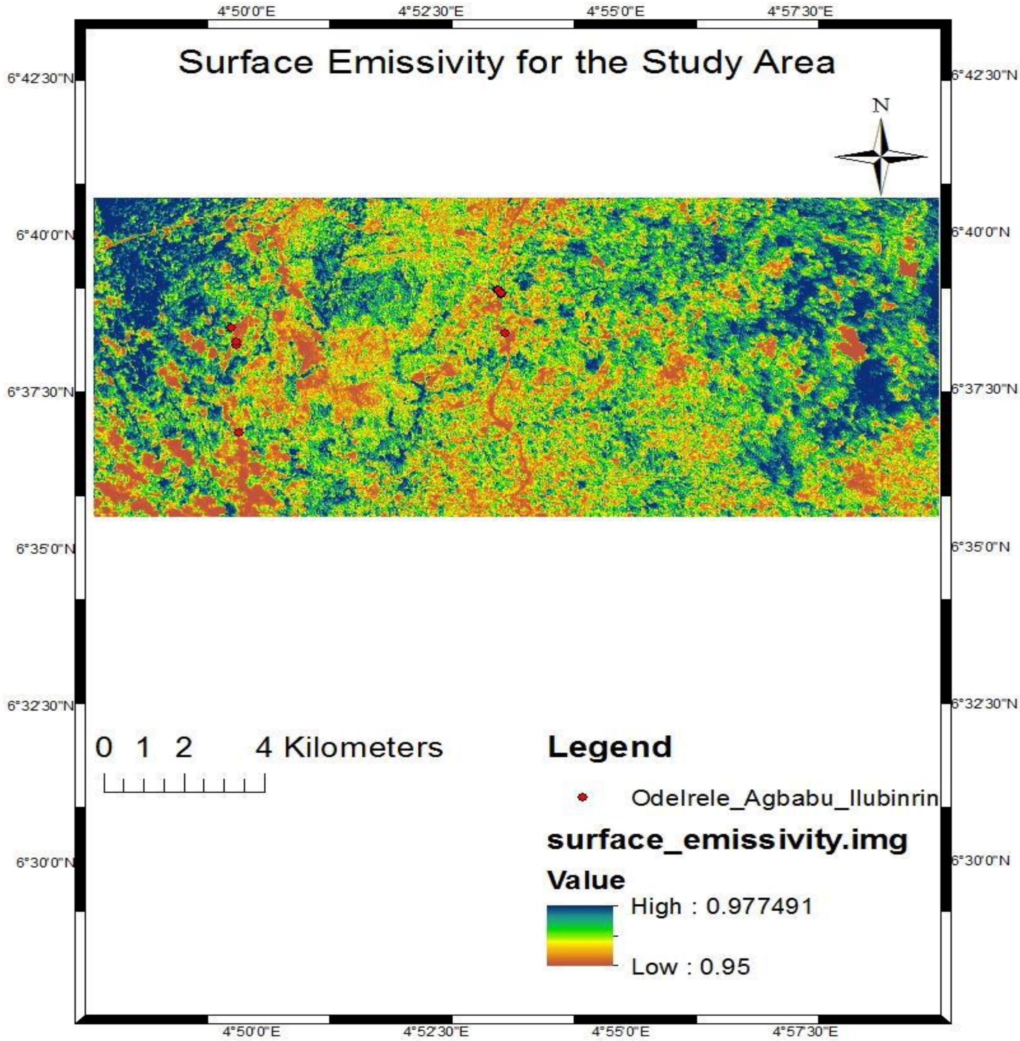

Fig 3: Surface emissivity of the area of study

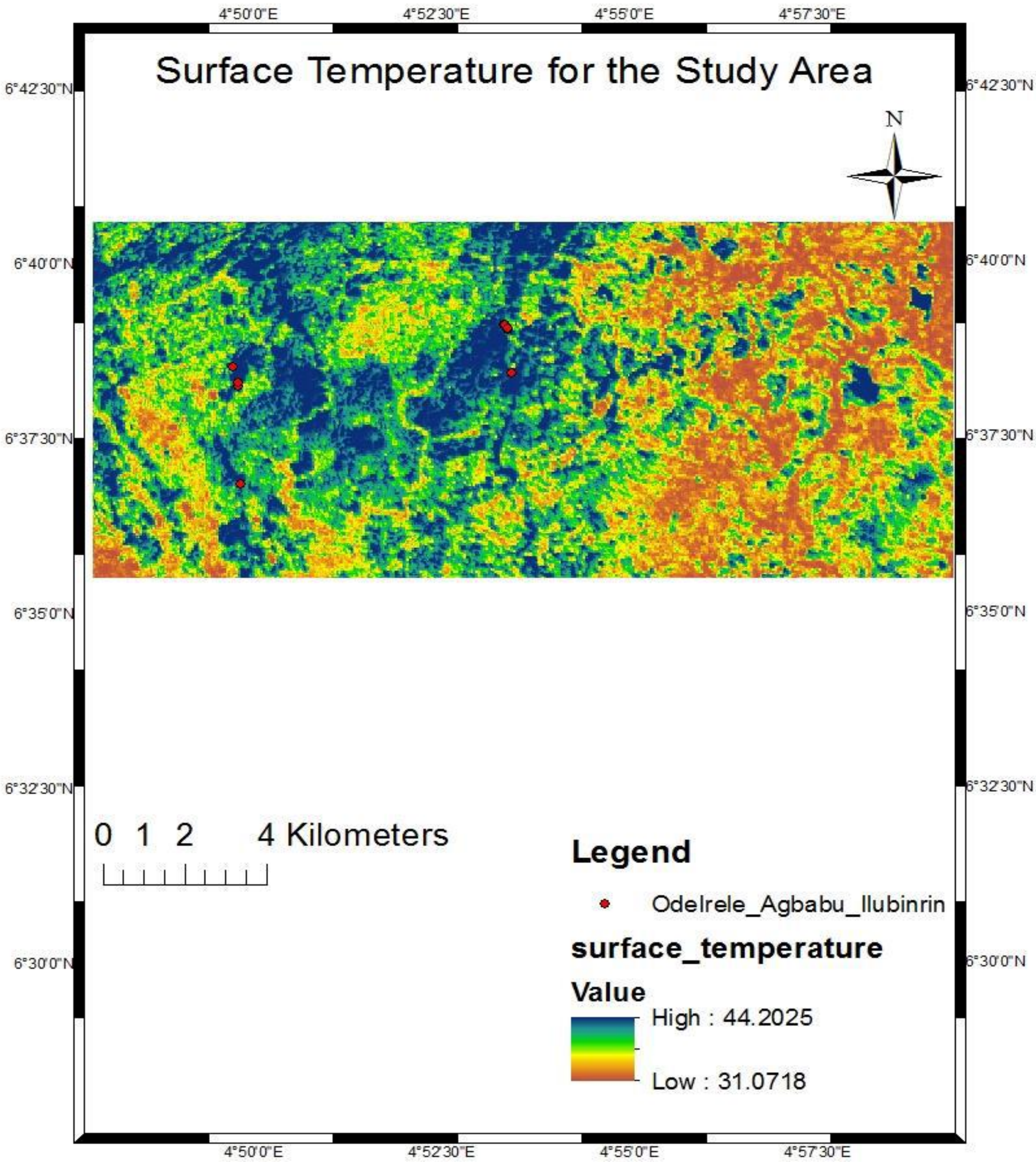

Fig 4: Surface temperature of the area of study.

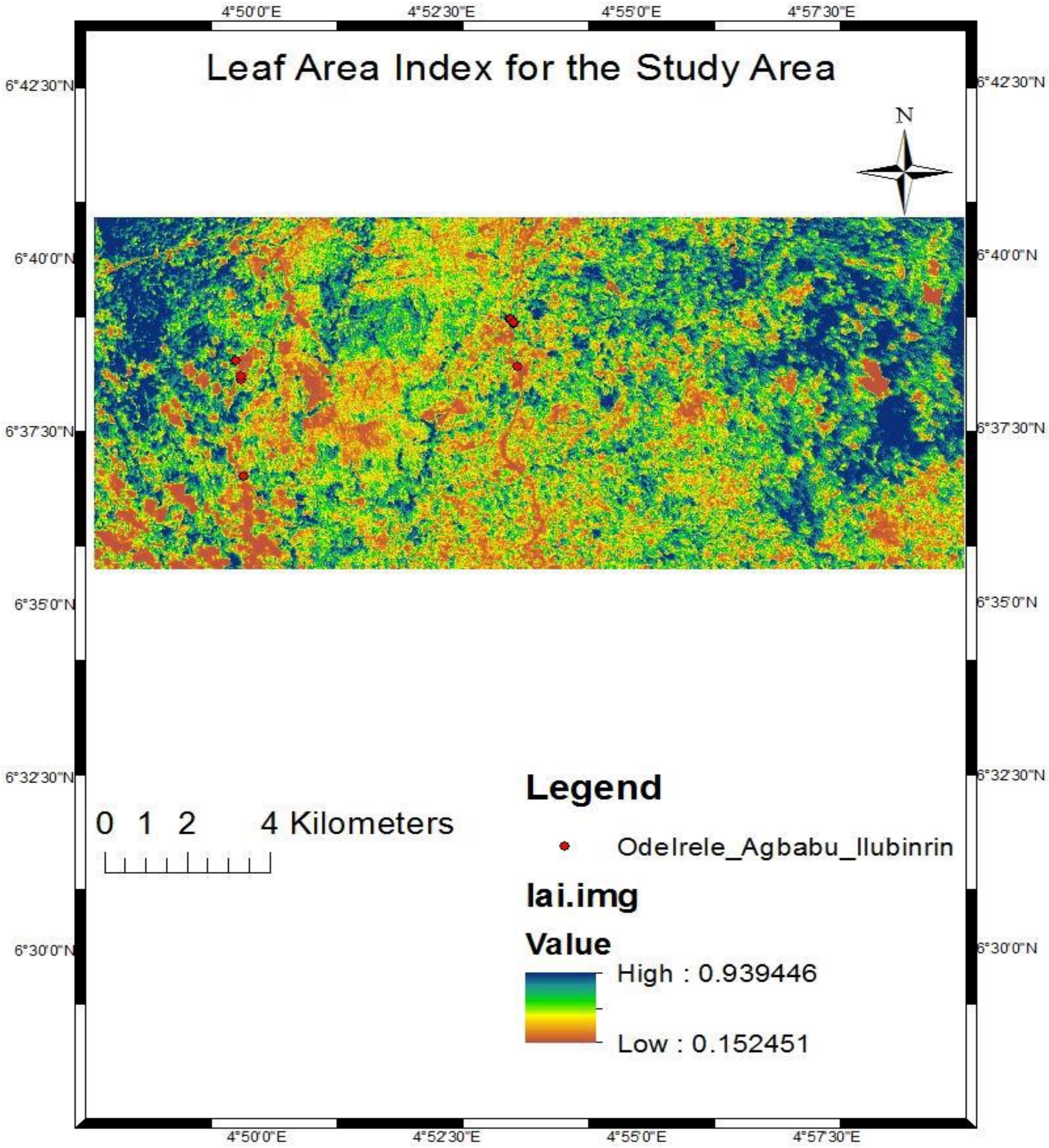

Fig 5: Leaf Area Index of the area of study

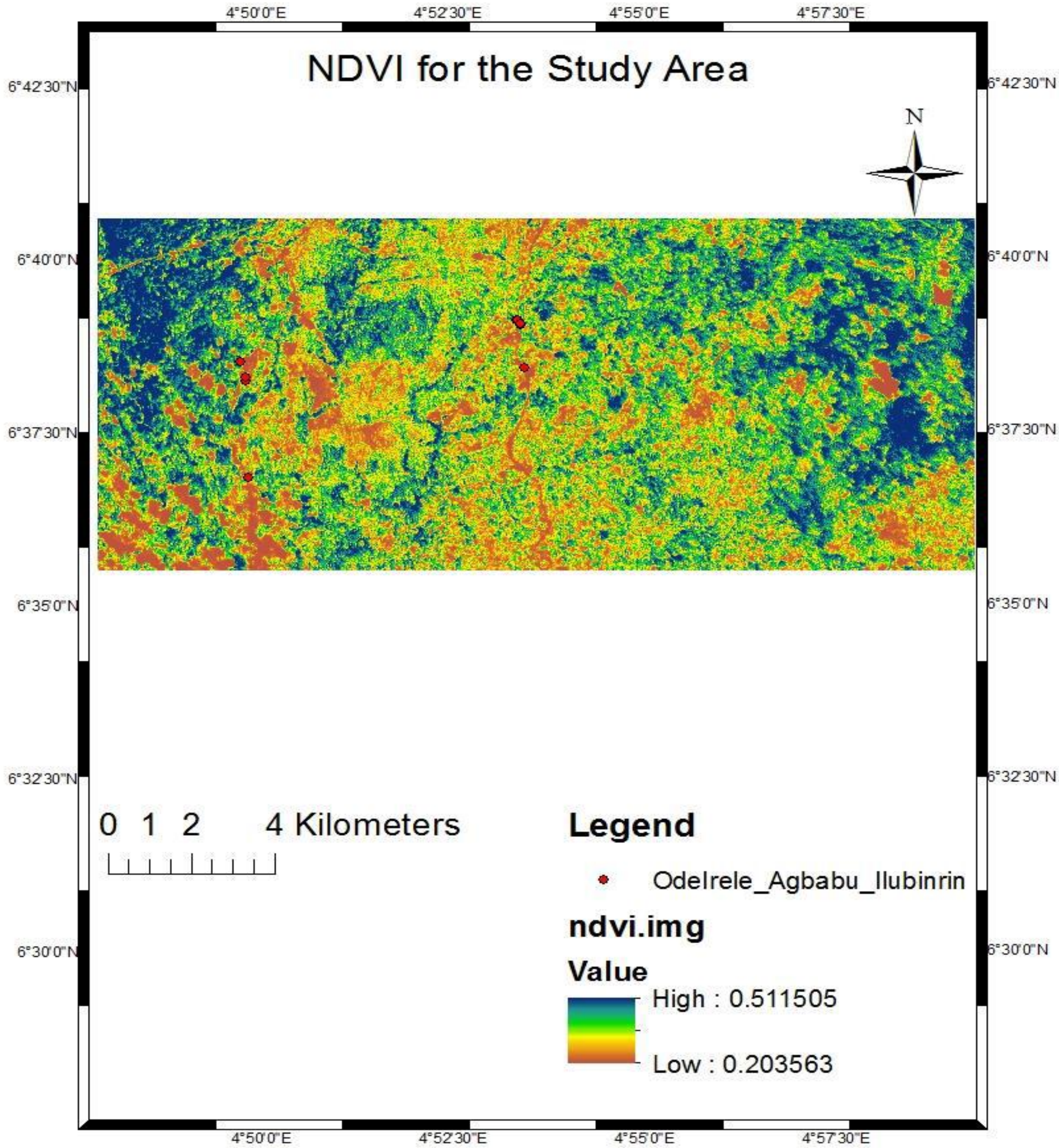

Fig 6: Normalized Difference Vegetation Index of the area of study

Surface albedo

Surface Albedo is the ratio of reflected radiation from the surface to incident radiation upon it or the proportion of incident light reflected by the surface. In Figure 7, the Surface Albedo value ranges from 0.16-0.37 which suggests that bitumen found in the study area has a high surface albedo.

Bitumen threshold

Thresholding technique involves using the spectral characteristics of the satellite (surface temperature and surface emissivity) of the known bitumen points of the study area to locate the unknown bitumen outcrops. The threshold value ranges from 0 to 1 (Fig.8). From Table 1, the known bitumen points of the area of study have a Threshold value of 1 which suggests that areas having a value of 1 has concentrated amount of bitumen and that areas having a value of 0 has little or no amount of bitumen. From the color scale, black indicates high amount of bitumen and white indicates low or no amount of bitumen.

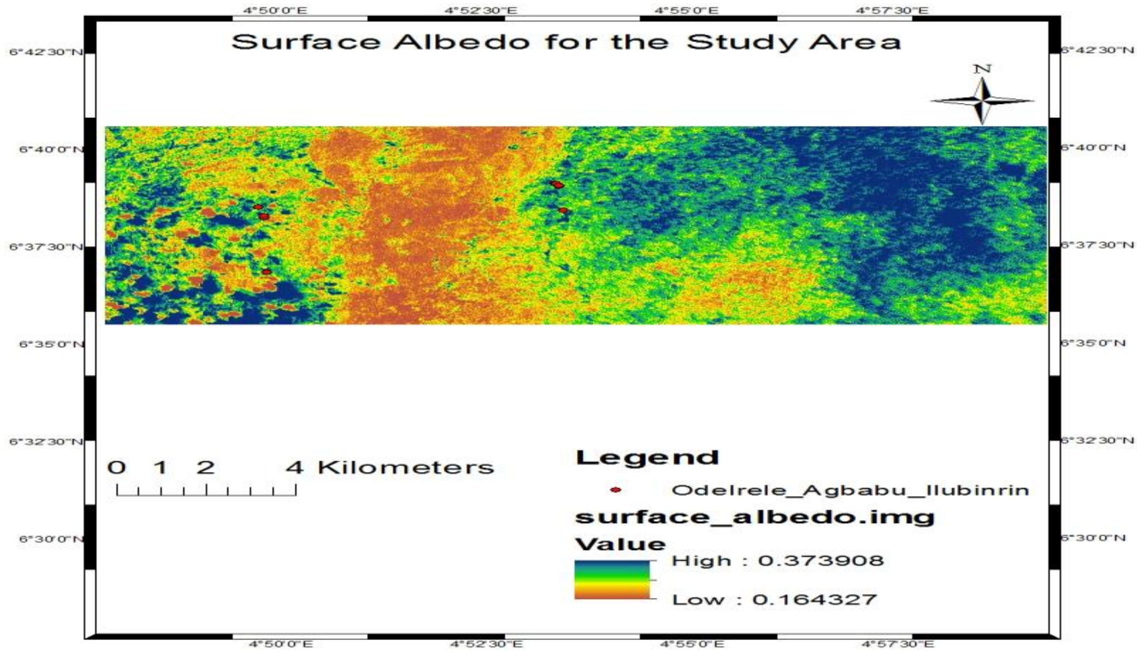

Fig 7: Surface Albedo of the area of study

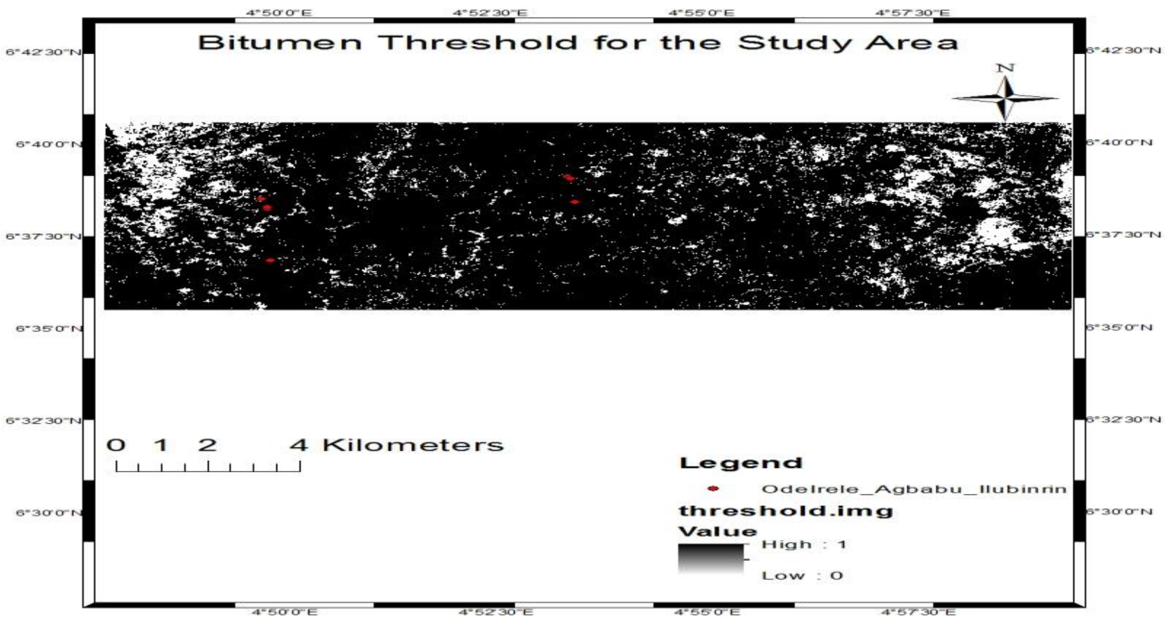

Fig. 8: Bitumen threshold of the area of study

VI. CONCLUSIONS

The spatial distribution of bitumen has been determined using remote sensing and GIS techniques. The results indicated that bitumen in Agbabu, Ilubinrin and Ode- Irele areas in Ondo State has high temperature, low emitting value, high Surface Albedo, low Normalized Difference Vegetation Index and low Leaf Area Index.

Most of the bitumen outcrops found in almost all the locations were under water which correlates with the study areas having low Leaf Area Index and low Normalized Difference Vegetation Index i.e. light vegetation The thresholding method also indicated that the unknown bitumen outcrops can be located using the spectral characteristics of the satellite (surface temperature and surface emissivity) of the known bitumen outcrops without directly coming into physical contact. The unknown bitumen outcrops might not be visible when visited on the field i.e. it might occur at the subsurface.

Geo-spatial tools like the Global Positioning System (GPS), Remote Sensing (RS), and Geographic Information System (GIS) have provided very powerful methods of surveying, identifying, classifying, mapping, monitoring, characterization, and to track changes in the composition, extent, and distribution of several forms of earth both resources renewable and non -renewable, living and non-living in nature.

The information presented is basic and a contribution towards locating the abundant bitumen resources at the study areas and also proved that satellite observations have become crucial for protecting the global environment and achieving sustainable development.

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