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# Remote Sensing-Based Assessment of the Impacts of Illegal Oil Bunkering Fire on the Vegetation

Ibochi Andrew Abah[1], Richard J. U.[2]
[1]Department of Surveying & Geoinformatics Federal Polytechnic, Bauchi, Nigeria
[2]Head Business Development, Office of the Surveyor General, Moscow Road, Port Harcourt, Nigeria
Email address: arndewabah4real @ gmail.com, jeremiah.uriah @ yahoo.com

***Abstract***— *Fire is a disaster occurring in different parts of the globe. Its occurrence may be natural if it occurred naturally or man-made if caused by human induced activities. Fire destroyed both living and non-living things, especially, materials that are more vulnerable to it. Oil bunkering fire is one of these fires that have impacted on the vegetation. Oil bunkering fire also has direct impact on the biodiversities. This study was selected to analyze the impacts of oil bunkering fire on the vegetation using remote sensing data and GIS software. Landsat satellite datasets of three epochs was selected for the study. Landsat 2003 is the pre fire image while Landsat 2015 and 2018 are the post fire images. It was downloaded from its archive using path 188 and row 57 and image pre-processing was carried out. The image was converted to spectral radiance using the algorithms specified in the Landsat metadata files. The spectral radiance images were used to compute dNBR for 2003 – 2015 and from 2003 – 2018. The study observed deteriorating vegetation from the computed dNBR values from 2003 – 2018 map. In the 2003 – 2015 map the minimum and maximum dNBR value was -561.03 and 398.43 and in the 2003 – 2018 map, the minimum and maximum values are -520.88 – 828.95, indicating increase severity of burnt vegetation in 2018. The study also observed very high severity of burnt vegetation in the vicinity of Bile and Ke (epicenter of oil bunkering). The study and the results obtained justify the usefulness of remote sensing data and GIS software to analyzed impacts of oil bunkering fire on the vegetation. Therefore, it is recommended that similar study should be extended to all Niger Delta states so as to identify and control further degradation of the ecosystem through illegal bunkering.*

***Keywords***— *Landsat Image, Fire, NBR, Oil bunkering, PANCROMATM, Spectral Radiance, Vegetation.*

## I. INTRODUCTION

Disaster weather natural or man-made is of different forms. Fire is one of the disasters that is ravaging the world. Fire can be cause naturally or by human induced [1]. Fire is seen as a chemical process that produced heat energy. It is produced when fuel (wood) react with oxygen to produce light energy. It occurrence depends on the availability of combustible materials such as wood, heat and oxygen [2]. Fire may occur in different ways such as wild fire, illegal oil bunkering fire, electric fire, chemical fire etc. It occurrence has impacts on both human and the vegetation. In Europe, an average of eight (8) in every one million people lost their lives every year due to fire disaster [3]. Also in Turkey, about 57 percent of its coastline forest is prone to fire disaster [1].The occurrence of fire and the associated effects include; global warming, ozone layer depletion, loss of wildlife habitat [1]. Others are, loss of soil fauna and flora, enhanced environmental degradation when the top soil is expose and destroyed the vegetation canopy.

Illegal oil bunkering fire is another form of fire that has destroyed the ecosystem. This fire have destroyed valuable natural resources and rendered the ecosystem less attractive to the people. Mapping and monitoring of the vegetation impacted by illegal oil bunkering become attractive with the introduction of remote sensing technology. [4] Defined remote sensing as the process of acquiring data about objects that are not in direct contact with the sensor, by gathering its inputs using electromagnetic radiation or acoustical waves that emanate from the target of interest. Remote sensing offers significant role in the mapping of vegetation impacted by illegal oil bunkering fire by allowing accurate delineation of the extent and severity of impacts. In this regard, several vegetation indices have been developed to study vegetation in term of burnt, health and greenness.

Normalized burn ratio (NBR) is one of the indices used in determining vegetation burnt area and the severity of the burnt. The model was developed by Key and Benson in 1996 for the purpose of mapping wildfires in national park. Accordingly, in other to introduced remote sensing into the NBR model, minor revisions were made between 2002 and 2003. With the emergence of remote sensing, large areas of burnt can be mapped with ease [5]; [6]. This has necessitated researchers in the field of remote sensing to utilize various dataset for the mapping of burnt areas. [7] Demonstrated the used of Landsat data from 2000 - 2007 to mapped forest fire in the three western North American. [1] Used NBR and NDVI derived from Landsat dataset to study burnt area in the Aegean Region of Turkey. In Indonesia, peat land fires were mapped using NBR and NDVI derived from SPOT-4 image [8]. [9] Have also shown the used of Sentinel -2 to mapped burned area in Italy. In Rivers State in particular, study was also carried out to determine the impact of oil spills on the vegetation [10]. Their study was carried out using Landsat dataset to compute vegetation areas impacted at pre and post oil spills. This study did not used NBR model but rather computed the vegetation from each image and subtracted the green from the non green vegetation. Another study in the Niger Delta was limited to the impacts of oil spills on water quality [11]. From the review, none of the researchers in the study area have used NBR model to study vegetation areas impacted by oil spills fire arising from bunkering related activities, which has been a major challenge to the oil companies and the impacted communities. This study was



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structured to use Landsat datasets to study the impacts of oil bunkering fire on the vegetation, using normalized burn ration (NBR) approach.

*1.2 Study Area*

The study area is Degema Local Government Area in Rivers State, South-South Nigeria. It is situated on longitude 06° 39’55”E - 07° 07’01”E latitude 04° 24’50”N - 04° 45’50”N in the WGS84. It has an approximate area of 1009.36ha with oil installations on its territory. The area is bounded in the south by the South Atlantic Ocean which also contributed to the availability of oil companies in the area. The topography is relatively flat, assuming that of the tidal flat topography of the Niger Delta region. It also has sedimentary rocks, similar to the Niger Delta area [12]. Degema is characterized by two main seasons (wet and dry seasons). The dry season is brought about by the northeast trade wind blowing from the Sahara desert [13]. In addition, the study area has annual precipitation and temperature of 2,601.6mm and 23.2°C respectively [13]. The area is dominated by mangrove forest due to its proximity to the South Atlantic Ocean. The dry lands are in isolated locations which are being used as settlements. The inhabitants are predominantly fishermen while some engage in trading activities. Some of the youths (those that wanted to make quick money) also engaged in illegal oil bunkering which is currently impacting on the ecosystem. This illegal activity has resulted in so many fire outbreaks in Degema, Rivers State. The Awoba pipeline fire which occurred on December, 2013 and other unreported fire directly caused by illegal bunkering constitute a problem to the ecosystem. Hence, this study area was selected in other to examine the prolong impacts of oil bunkering on the vegetation using vegetation index (VI).

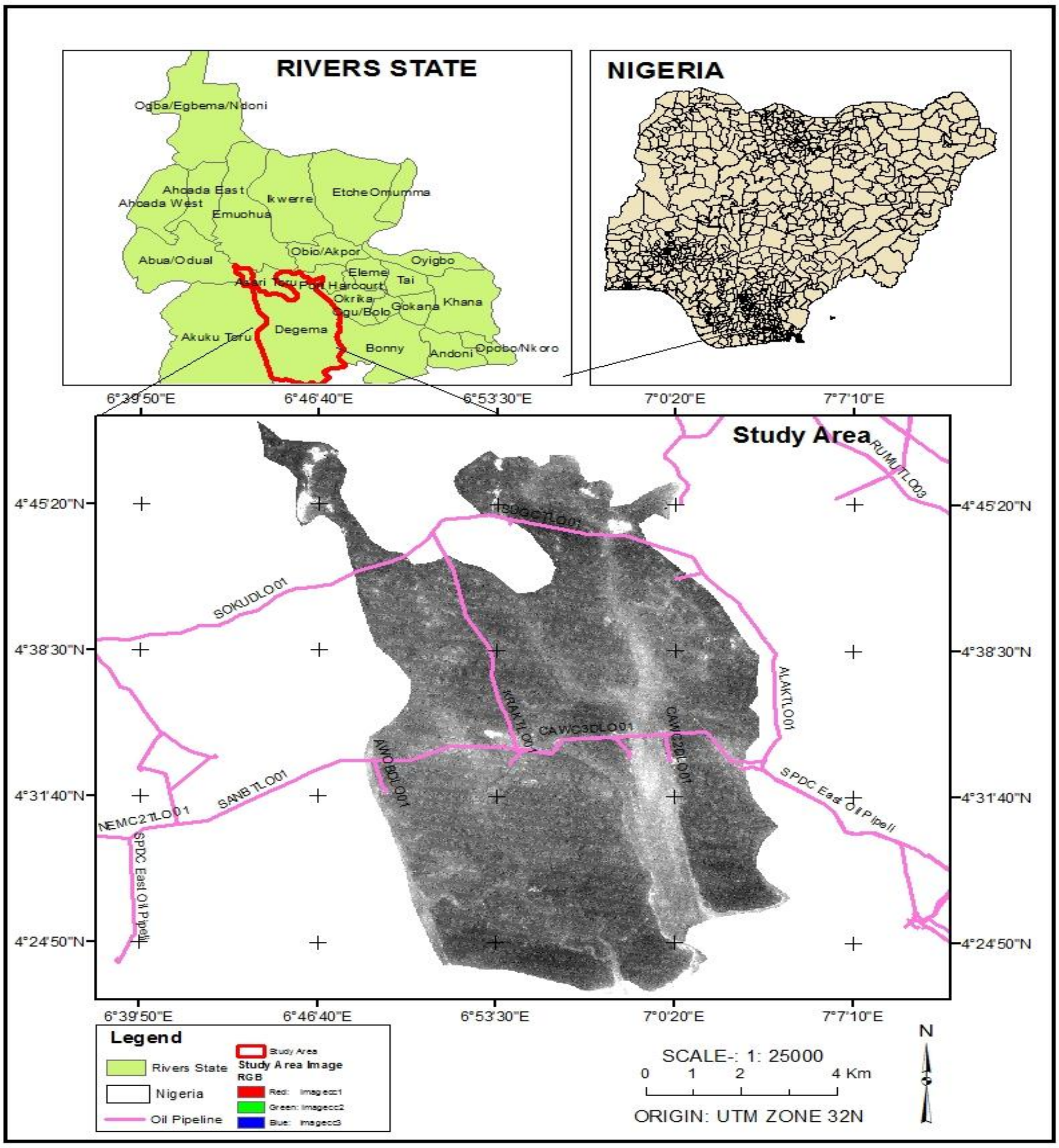


Figure 1. Study area location map produced from Landsat image with the pipelines overlay.

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## II. METHODOLOGY

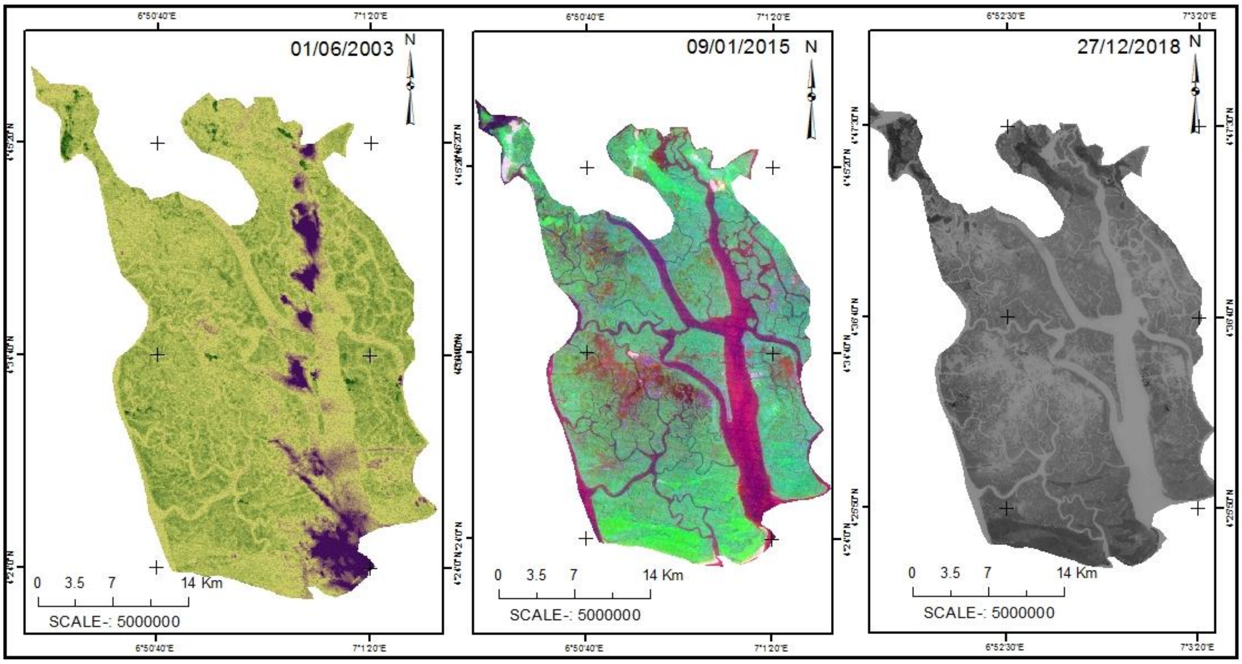
### *2.1.1 Dataset used*

Dataset is a collection of data use for the implementation of particular study. The dataset used for the study of the impacts of illegal oil bunkering fire on the vegetation are satellite derived, mainly from Landsat imageries. The characteristic of the Landsat data used for the study is shown in table 1.

TABLE 1. Landsat datasets used for burnt area by oil bunkering.

| Data | Date | Resolution (m) | Source | Band Use |
|---|---|---|---|---|
| LANDSAT ETM+ | 01/06/2003 | 30 x 30 | http://glovis.usgs.gov/ | B4, B7 |
| LANDSAT ETM+ | 09/01/2015 | 30 x 30 | http://glovis.usgs.gov/ | B4, B7 |
| LANDSAT OLI | 27/12/2018 | 30 x 30 | http://glovis.usgs.gov/ | B5 B7 |

NOTE: ETM + = Enhanced Topographic Mapper Plus, OLI = Operational Land Imager




2a 2b 2c

Figure 2. Composite band of pre-fire image (2003) as 2a and figure 2b and 2c is the composite of post-fire image (2015 and 2018) respectively.

### *2.1.2 Softeware Used*

(a) PANCROMA™: This is remote sensing image processing software which can be purchase from the link www.PANCROMA.com. The software was used to remove gaps (no data) in the Landsat image caused by the failure of the scan line collector (SLC) in the sensor.

(b) ESRI's ArcGIS 10.3.1: The software was selected because of its strength in raster data computation. Key operations performed with the software include: image clipping, conversion of DN to spectral radiance, computation of NBR and dNBR.

### *2.2 Data Processing*

Landsat satellite image was used for the study of the impacts of oil bunkering fire on the vegetation. The Landsat multispectral scanner system (MSS) for earth observation and monitoring was first launched into orbit on 23 July, 1972 [14]; [15]. Over time, Landsat technology keeps evolving with the improvement in spatial and spectral capability between 16 July 1982 (the launched of Thematic Mapper) and 15 April 1999 (the launched of Enhanced Thematic Mapper plus) [14]. This evolution in Landsat satellite technology necessitated the enormous applications of its data. [5] Has emphasized the application of Landsat for burnt area assessment.

Landsat satellite image used for burnt area assessment was downloaded from its website (http://glovis.usgs.gov/) free-of-charge. The download was done using the selected path and row arrangement of the defined area. In this case, path 188 and row 57 was used to download the image in zip file format. The zipped image was unzipped into a known folder with the metadata file identified for further analysis.

The 09/01/2015 Landsat data contained gaps (no data) in the image. These gaps were corrected using PANCROMA software. The software was basically design for the correction of Landsat strip line problems. Landsat sensor developed strip line errors due to failure of the Scan Line Collector (SLC) in May 31, 2003 [16]. The corrections were carried out using 27/12/2015 image as no gap image and 09/01/2015 as gap image. The method chosen for the removal of gaps in the image is the Hayes interpolation method [17]. There are three main stages involved in image gap filling operations, namely; (a) compute common extent (b) subset the image (c) run gap fill algorithm. The gap image was corrected for the strip lines and used in the analysis of burnt area due to oil bunkering.



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*2.2.1 Computation of NBR*

Prior to the NBR computations, image clipping was done in other to confine the image to the study area. It is an image processing stage where shapefile for the study area was used to clip the image extent [18]. Clipping operation was done in ESRI's ArcGIS 10.3.1 band by band and the images saved into the project folder. The raw image which was in digital count (DC) was converted to image in radiance (true reflection of earth surface features) and that which represent measurable physical quantity [19], However, this work relied on the formulae quoted in the Landsat user's guide for the conversion of DC from the raw image to spectral radiance.

For the Landsat ETM+ used for this study, spectral radiance in $Wm^{-2}Sr^{-1}$, was computed using the formula,

$$L_\lambda = (LMAX_\lambda - LMIN_\lambda)/ QCALMAX - QCALMIN \times (DN - QCALMIN) + LMIN_\lambda \quad (1)$$

Where,

$LMAX_\lambda$, and $LMIN_\lambda$ are the maximum and minimum spectral radiance for the band, QCALMAX and QCALMIN are the maximum and minimum quantize calculated for the band, and DN is the raw image in DC [20]; [21].

Similarly, for the Landsat OLI, spectral radiance in $Wm^{-2}Sr^{-1}$, was computed using the formula,

$$L_\lambda = M_L \times Q_{cal} + A_L \quad (2)$$

Where, $M_L$ is the radiance multiplicative scaling factor for the band, $Q_{cal}$ is the L1 pixel value in DC and $A_L$ is the radiance additive scaling factor for the band [20], [22].

The radiance image was used to compute NBR for each image. For the Landsat 7, the bands selected for the computation of NBR are band 4 (near infrared) and band 7 (shortwave infrared). Band 4 falls within the electromagnetic spectrum (EMS) range of 0.76 – 0.90µm while band 7 ranges from 2.08 – 2.35µm. The bands (4 and 7) are useful in the study of soil and vegetation moisture content [23]; [24]. NBR according to [25]; [5] are given by the formula'

$$NBR = B_4 - B_7/ B_4 + B_7 \quad (3)$$

Where, $B_4$ is the infrared band and $B_7$ is the shortwave infrared band of the Landsat data.

Similarly, for Landsat OLI, the bands used are 5 and 7. Landsat 8 band 5 is the near infrared band located in the wavelength range 0.85 – 0.88 µm and band 7 is the shortwave infrared ranges from 2.11 – 2.29 µm [26]. Hence, for Landsat OLI, NBR is computed using the formula,

$$NBR = B_5 - B_7/ B_5 + B_7 \quad (4)$$

Where, $B_5$ is the infrared band and $B_7$ is the shortwave infrared band. [27] Also used Landsat OLI formula to mapped forest fire.

NBR value theoretically ranges from -1 to +1 characterizing the various vegetation level of burnt. According to [5] NBR values near zero (0) represent burnt vegetation while value near one (1) implies healthy and green vegetation. NBR was computed for the three epochs (images of 2003, 2015 and 2018) respectively. This is necessary to calculate the difference in fire burnt due to oil bunkering activities over the periods. The difference in burnt is given by the formula;

$$dNBR = NBR_{prefire} - NBR_{postfire} \quad (5)$$

Where; dNBR is the difference in burnt from 2003 to 2015. $NBR_{prefire}$ is the pre fire which is 2003 and $NBR_{postfire}$ is the post fire, that is, 2015. Similarly, the difference in burnt between 2003 and 2018 was also calculated. In the calculation, 2003 image represent pre fire while 2018 is the post fire image. In the pre fire, bunkering activities have not been pronounced until 2018 which was seen as the peak of the activities. Ideally, dNBR values should range between -2 to +2 [25]; [5]. This is often scaled by factor of $10^3$, given a range in values from -500 to 1,300 and that this produced a seven severity level of burnt ranges from high regrowth (-500 to -251) to high severity (+660 to +1,300) of burnt [5]. According to their works, higher values of dNBR indicates that the vegetation is low in chlorophyll content, implying unhealthy vegetation due to burn. Similarly, lower dNBR values imply that the vegetation is highly rich in chlorophyll, indicating very strong reflection from the band 4. These scales were adopted to investigate burnt vegetation due to oil bunkering activities in the study area.

## III. Results and Discussion

The stretched NBR for each epoch was computed and the results are shown in figure 3.1a - c. For the 2003 stretched NBR map (used as pre fire image), the value varies between 0.35 minimum and 1.04 maximum. The values of the 2015 NBR map defers from the 2003 map. The NBR value of the 2015 map varies from maximum 1.03 to minimum 0.60. Similarly, 2018 highest and lowest NBR values are 0.01 and 0.97 respectively. Table 3.1 shows the minimum and maximum NBR values indicating the varying degrees of burnt obtained in the study area.

TABLE 3.1. Statistical reports of the minimum and maximum NBR values.

| NBR | 2003 | 2015 | 2018 |
|---|---|---|---|
| Minimum | 0.35 | 0.60 | 0.01 |
| Maximum | 1.04 | 1.03 | 0.97 |
| Mean | 0.70 | 0.82 | 0.49 |

For the purpose of understanding the degree of burnt, NBR for each map was reclassified into five classes using equal class interval. The 2003 NBR map was not reclassified because of the absence of burnt vegetation during the period. Only the 2015 and 2018 maps adopted as post fire images were reclassified. Accordingly, for the 2015 NBR map, the values were reclassified into five classes ranging from 0.60 – 1.03. The first class represented with red ranges from 0.60 – 0.77, it was followed by class represented with Rhodolite Rose ranging from 0.77 – 91. The third class ranges from 0.91 – 0.94 and was indicated by Lemon Grass. This class represents the moderate severity of burnt vegetation. The forth and the fifth classes are in the range 0.94 – 0.95 and 0.95 – 1.03 indicating low and very low severity of burnt. The final image which is the 2018 NBR map, the values varies between 0.01 – 0.97. From the 2018 NBR map, low value indicate burnt vegetation while higher values indicates no burnt or less burnt vegetation. The red polygons on the maps showed the burnt vegetation on the post fire images (2015 and 2018).



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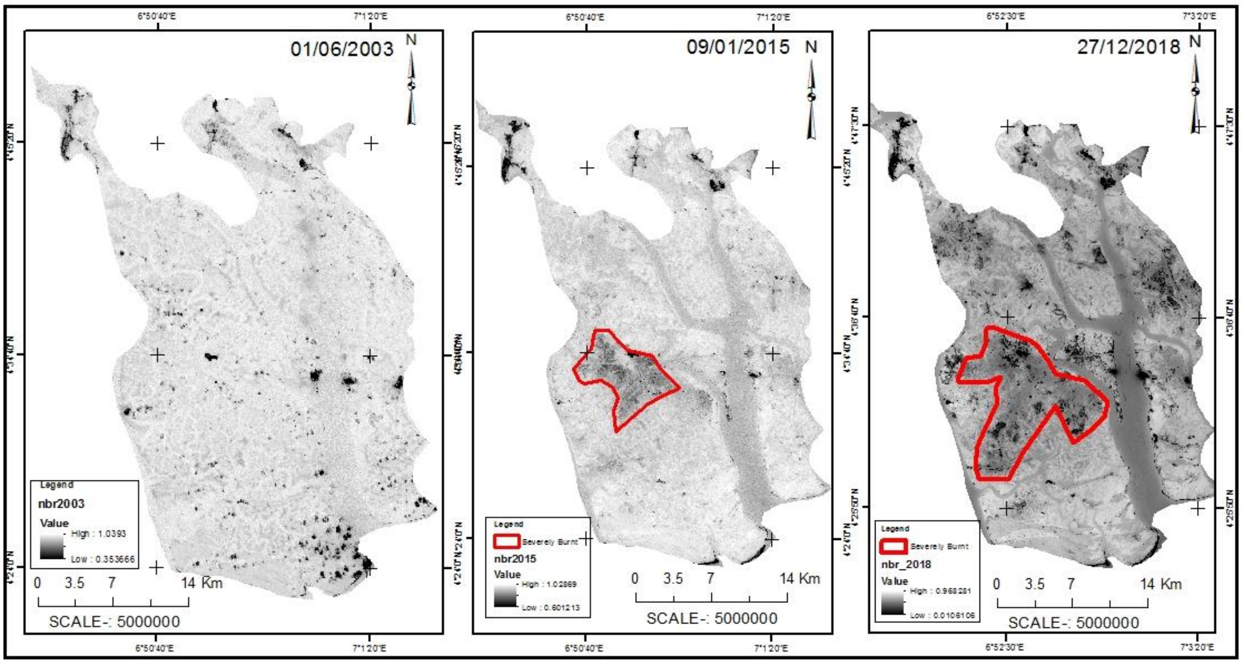
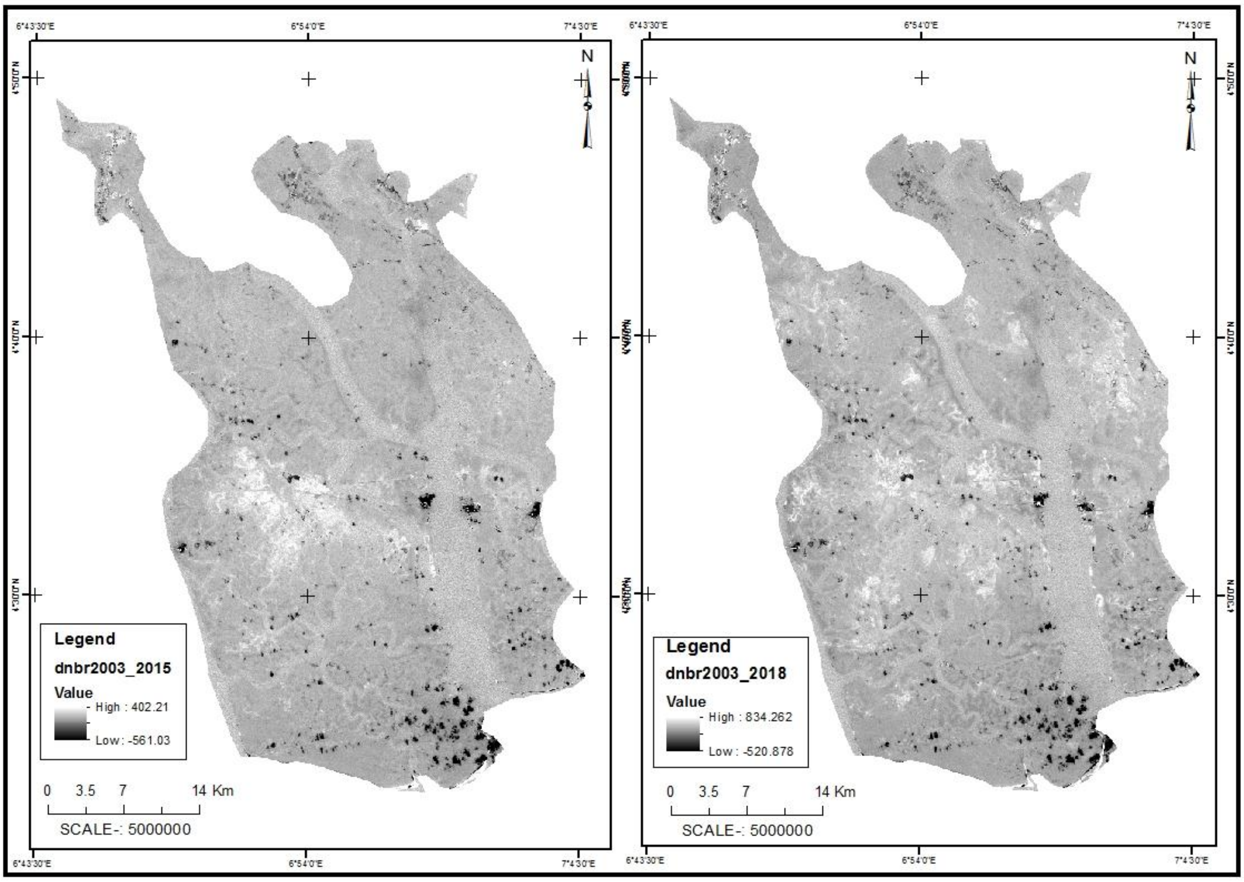



3.1a 3.1b 3.1c

Figure 3.1a – c. The computed stretched NBR for the 2003, 2015 and 2018 map.




3.2a 3.2b

Figure 3.2a and 3.2b. The Stretched dNBR for the 2003 – 2015 and 2003 - 2018 map showing severely burnt areas in white patches.

Furthermore, in determining burnt vegetation by oil bunkering activities, the difference in NBR (dNBR) was calculated. The results of the stretched and reclassified dNBR maps were shown in figure 3.2a – b and 3.3a – b. Firstly, was

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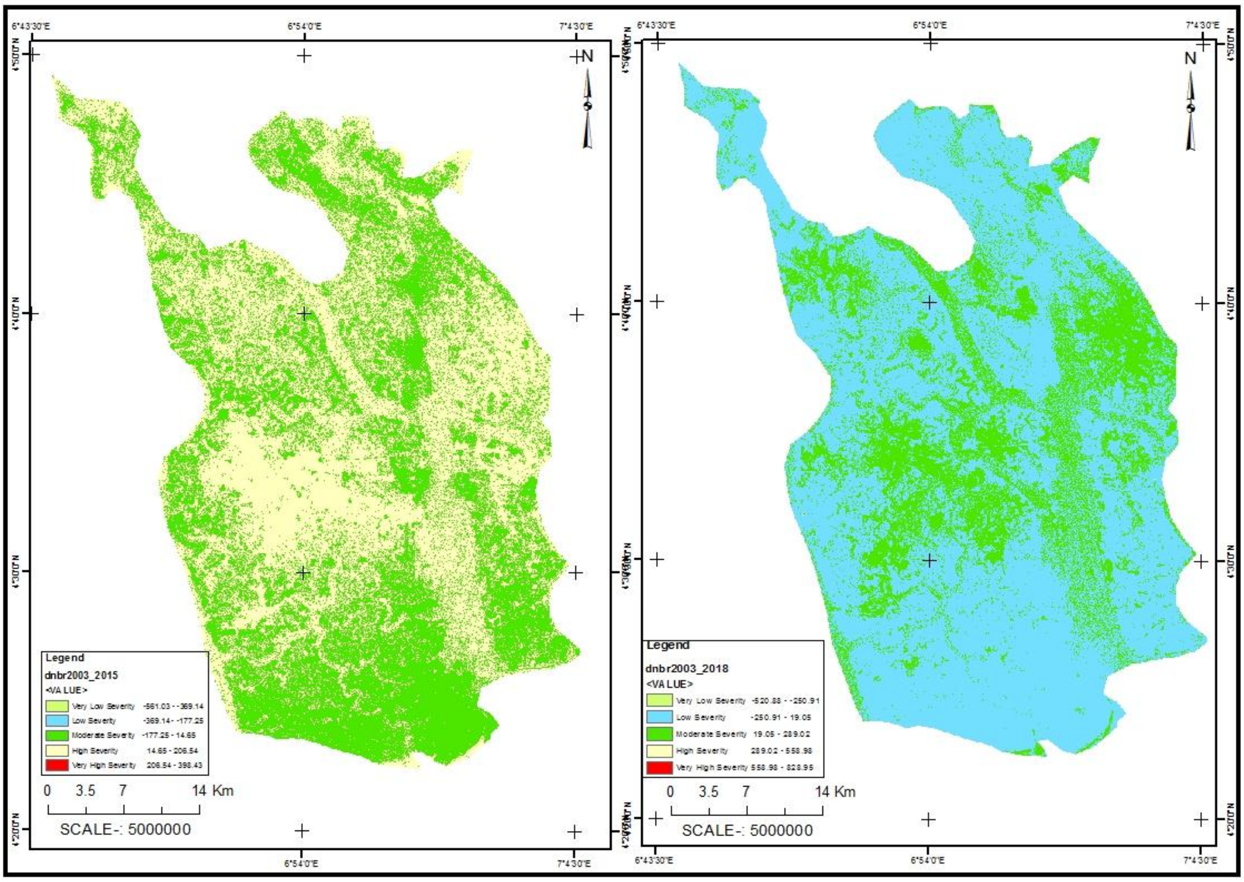
the computation of the difference 2003 – 2015 and the values scaled by 1000 to produced second dNBR map. The scaled map was classified into five classes. The class ranges from very low severity to very high severity of burnt. The first class value ranges from -561.03 - - 369.14. This class represents the very low severity of burnt. The first class was followed by a second class named low severity of burnt, ranges from -369.14 - -177.25. The third class ranges from -177.25 – 14.65 with the class name moderately severity of burnt. The forth class ranges from 14.65 – 206.54 and this class represents high severity of burnt. The final class ranges from 206.54 – 398.43 represented with red is the very high severity of burnt vegetation. The classes are represented with unique colours in other to distinguish them.

Similarly, for the 2003 – 2018 map, the dNBR was calculated. In this map, very low severity of burnt ranges -520.88 - -250.91. This class was followed by low severity of burnt with the values ranges from -250.91 – 19.05 represented with Apatite blue. The moderately severity of burnt occurred in the range 19.05 – 289.02 represented with Quetzel Green. This particular class occurred more in the western location of the map. The high severity of burnt ranges from 289.02 - 558.98, indicated on the map with Yucca Yellow. The last class which is the very high severity ranges from 558.98 – 828.95 and was represented with red.




3.3a 3.3b

Figure 3.3a and 3.3b. Reclassified dNBR 3.3a for the 2003 – 2015 and 3.3b for 2003 - 2018 map.

TABLE 3.2. Statistical reports of the minimum and maximum dNBR values scaled by 1000.

| dNBR | 2003 - 2015 | 2003 - 2018 |
|---|---|---|
| Minimum | -561.03 | -520.88 |
| Maximum | 398.43 | 828.95 |
| Mean | -81.30 | 154.04 |

### *3.2 Discussion*

Taking critical look at the NBR maps, it will be observed that the burnt vegetation area increases from 2015 to 2018. For instance, in 2015 the severely burnt area occurs more in the western map location. These areas appeared as white patch on the map with NBR value 0.60. The severely burnt area occurred within the neighbourhood of Bile and Ke town. The burnt vegetation also occurred along multinational oil company pipelines where the oil bunkering activities are actually carried out on daily basis. The pipelines which traverse the area as obtained from FUGRO are the SANBT001 (crosses from west to east), KRAKTL001 (running northwards), and the BUDCTL001 situated in the northern map location from west to east.

In 2018, the NBR values decrease further to 0.01 due to continuous oil bunkering related activities popularly called by the local people Kpo-fire. The decrease in NBR value to 0.01 indicates that the vegetation is severely burnt by oil bunkering fire and also suggested progressive oil bunkering activities. Also, healthy vegetation is continuously decreasing from 1.03 in 2015 to 0.97 in 2018 due to these illegal activities. Also in 2018 the burnt vegetation area extends to other location, indicating an increase in the bunkering fire.

The dNBR map also reveals the increase in burnt vegetation from 2015 to 2018. In 2015 the maximum value is 398.43 indicating very high severity of burnt while in 2018 the values increase to 828.95. Burnt severity has increase by 430.52 from 2015 to 2018. The burnt effects has not only limited to the western map location (around Bile and Ke) as in the case of 2015 but has extended to the east and north where the bunkering activities are on the increase. Severe burnt was also noted within the oil field in Ojekiri and Esuma covering a total area of 36.80sq.km. This increase may be due to the involvement of other communities, tribes, and improve technology in oil bunkering. So many tribes have been migrating to Degema for the purpose of opening and operating oil bunkering sites. These illegal oil activities have led not only the destruction of the vegetation as demonstrated by the dNBR maps but to the extinction of biodiversities in the impacted areas. The recent soot in all parts of the Rivers State, including the capital Port Harcourt is a product of kpo-fire. The state government has set-up committee to investigate the causes of the soot in other to proffers lasting solution for it.

## IV. Conclusion

Oil bunkering fire occurred in the study area on regular basis with varying degrees of impact on the vegetation. Vegetation is the most impacted land cover by the fire due to its vulnerability to fire. The introduction of remote sensing offers useful approach to analyze these impacts. Several indices have been used in the field of remote sensing and GIS to study vegetation health and greenness, but in this study, normalized burn ration (NBR) was used to study impacted vegetation by the oil bunkering fire. The analysis of the burnt vegetation in the study area was carried out using Landsat satellite datasets of three epochs. The Landsat satellite data obtained from its archive in digital number was converted to spectral radiance. NBR and dNBR was computed for each epoch and the results indicated that severity of burnt vegetation increase from 2015 to 2018. The study also reveals that burnt vegetation occurred mostly around Bille and Ke periphery. For further study, other vegetation indices like normalized difference vegetation index (NDVI) should be use to study vegetation health impacted by oil bunkering activities.

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