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Spectral Indices for Detecting Change Trend in Vegetation affected by Hydrocarbon Spillage

Esther Oluwafunmilayo Makinde[+]

Laboratory for Geoinformatics Research, Department of Surveying and Geoinformatics, University of Lagos, Lagos, Nigeria

Abstract. Geo-informatics and in-situ technologies have made it possible to quickly assess, monitor and analyse vegetation biodiversity accurately in a non-destructive way. The goal of this study was to investigate the change trend based on the absorbance or reflectance of certain wavelengths of light by vegetation using spectral vegetation indices in Ogun state, South-West of Nigeria. Satellite images were obtained and ground hyperspectral data acquired with a ground-based integration system called Analytical Spectral Device (ASD) Handheld2 Spectrometer. Spectral indicators were calculated from both systems were analysed and compared. The information derived from the analyses had shown the potential to monitor the changes of affected vegetation.

Keywords: Indices, Wavelength, Geo-information, Spectrometer

1. Introduction

Geo-information technique is useful in several modes of hydrocarbon spillage and spillage control, including large area surveillance, site specific monitoring and tactical assistance in emergencies; and is able to provide essential information to enhance strategic and tactical decision-making, decreasing response costs by facilitating rapid oil recovery and ultimately minimizing impacts [1]. Large areas impacted by spill that causes a patch on bare soil or change vegetation reflectance can be mapped using airborne sensors [2]. Studies have shown that expert knowledge and additional information such as maps of the geology, soil type or vegetation type improves the classification results significantly [3].

In-situ study minimizes field data collection time while maximizing the quality of spectral results over a range of wavelengths; and produces laboratory-quality results in remote measurement and analysis applications, and in a range of orientations and environments [4]. Research has shown that the handheld spectrometer/radiometer was used to obtain the correlation between spectral observations with vegetation characteristics, yields and stress [5, 6]. Indicators such as spectral indices were developed on the simple mathematical formula at given wavelengths to describe condition of vegetation and estimate the quantity of biomass based on its reflectance [6]. Normalized Difference Vegetation Index (NDVI), the most frequently used is the combination of its normalized difference formulation and use of the highest absorption and reflectance regions of chlorophyll make it robust over a wide range of conditions including photosynthetic activity [7]. RVI is the ratio vegetation index is the use of band ratios to eliminate various albedo effects [8].

The ratio of near-infrared (NIR) to red as the vegetation component of the scene is used where the highest reflectance; absorption bands of chlorophyll makes it both easy to understand and effective over a wide range of conditions. [9]. Also, RedEdgeNDVI an index is the Red Edge band that is spectrally located between the Red band and the NIR band without overlap where the red portion is one of the areas where chlorophyll strongly absorbs light and the NIR is where the leaf cell structure produces a strong reflection.

[+] Corresponding author. Tel.: +2348030799879.
E-mail address: estherdanisi@gmail.com.

Therefore, variations in both the chlorophyll content and the leaf structure are often reflected in the Red Edge band [10]. Accordingly, several studies have suggested that this band is able to provide additional information in order to identify vegetation types, nutrition and health status, and characterize vegetation cover and abundance, among other features [11]. Also, the Vogelmann RedEdge Index 1 (VOG1) is a narrowband reflectance measurement that is sensitive to the combined effects of foliage chlorophyll concentration, canopy leaf area, and water content. Applications include vegetation phenology (growth) studies, precision agriculture, and vegetation productivity modelling [12]. Soil-adjusted vegetation index (SAVI) or Optimal Soil Adjusted Vegetation Index (OSAVI) is a transformation technique presented to minimize or remove soil influences from spectral vegetation indices involving red and near-infrared (NIR) wavelengths [13]. The objective of this study was to investigate the change trend by assessing the changes in the spectra of impacted vegetation and compare vegetation indices derived from both image and ground-based measurements taken by the integration system.

2. The Problem

Oil pipeline rupture and the attendant hydrocarbon spillage and spill; explosion and fire are common occurrences in Ogun State, Nigeria. The pipelines laid along the mainlines and booster pump stations to the storage depot in Mosimi depot have not been replaced since it was first laid over 25 years ago. Therefore, damages and rupture are inevitable. Also, pipeline sabotage is still the largest contributor to hydrocarbon/oil seepage and spill. Interfering with oil pipelines and installations through vandalization/fuel scooping, oil bunkering and oil terrorism has assumed huge dimensions and a variety of forms. This has increased the amount of hydrocarbon spillage into the environment that has gone unnoticed. Hydrocarbon spillage only made public when it results in an explosion that cannot be curtailed immediately by the saboteurs. This hydrocarbon spillage can cause severe damage to the environment in general and vegetation in particular when they leak into the soil thereby posing great threat. The influence of these human induced destructive occurrences on vegetation biodiversity change trend in Southwest Nigeria has not been well documented.

3. Materials and Methods

3.1. The study area

The ground-based measurement of this study was carried out in randomly identified impacted sites of Obafemi-Owode Local Government Area in Ogun located in South West Nigeria, West Africa lying within latitudes 7°00′N 3°35′E, 7°00′N 3.583°E and 7°00′N 3°35′E, 7°00′N 3.583°E (Fig. 1). Ogun is not only a creek and lagoon region, it is also blessed with a coastal plain with the elevation increasing northwards from above 40m to 250m above the sea level. The undulating plain is broken by the North West / South East sandstone extending from near Aiyetoro in Yewa zone eastward to Ijebu-Igbo. There are pockets of rocky outcrops dotting the landscape especially around Abeokuta. There is a network of oil pipeline in Ogun, thereby making its area prone to constant hydrocarbon spillage due to persistent vandalization of these pipelines.

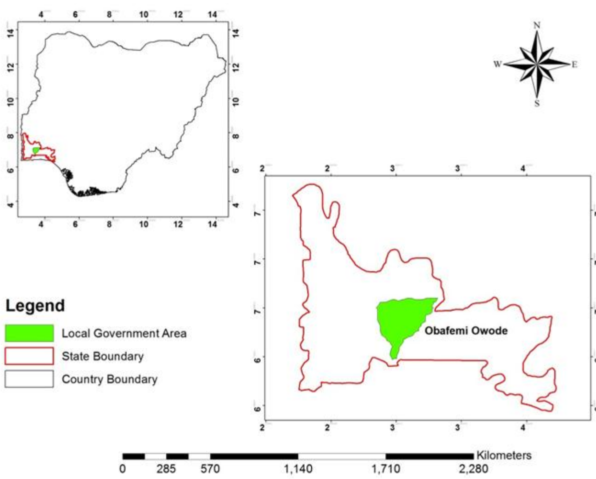

Fig. 1: Map of the Study Area

The ground-based measurement of this study was carried out in randomly identified impacted sites of Obafemi-Owode Local Government Area in Ogun located in South West Nigeria, West Africa lying within latitudes 7°00′N 3°35′E, 7°00′N 3.583°E and 7°00′N 3°35′E, 7°00′N 3.583°E.. Ogun is not only a creek and lagoon region, it is also blessed with a coastal plain with the elevation increasing northwards from above 40m to 250m above the sea level. The undulating plain is broken by the North West / South East sandstone extending from near Aiyetoro in Yewa zone eastward to Ijebu-Igbo. There are pockets of rocky outcrops dotting the landscape especially around Abeokuta. There is a network of oil pipeline in Ogun, thereby making its area prone to constant hydrocarbon spillage due to persistent vandalization of these pipelines.

3.2. Data collection and analysis

The product of the constellation of 5 satellites, the RapidEye multispectral satellite image of 5 m resolution covering Ogun state for 2009 and 2011 were acquired (Fig. 2) and subjected to digital image processing (DIP). The locations of areas impacted by hydrocarbon spillage were identified on the field using a handheld Global Positioning System (GPS) with an accuracy of -/+5m of which A, B, C and the C' (control) were selected randomly and subsequently identified on the satellite images. Field study was carried out on three identified impacted areas of 30 m by 30 m and mapped out. Control plot was established in undisturbed vegetated areas away from but perpendicular to the source of hydrocarbon spillage, the pipeline. These fields were measured for spectra reflectance and relative chlorophyll content present in the vegetation leaves, using the Analytical Spectral Device (ASD).

Every 10 minutes, reference measurements were taken of White Spectralon Panel for the internal calibration of the instrument. Since leaf pigments are important determinants of reflectance in the visible and near infrared wavelengths, spectral indices such as NDVI, RVI, RedEdgeNDVI, VOG1 and OSAVI were calculated within varying wavelength. Compensation for differences in reflectance owing to varying leaf angles made for [14]. The ASD field spectroscopy measurement data were acquired in the standalone mode and were processed using HH2 Syn and ViewSpecPro software applications. Further analysis involved the creation of spectral library for all the spectral field measurements to enable averaging and analyses of indices.

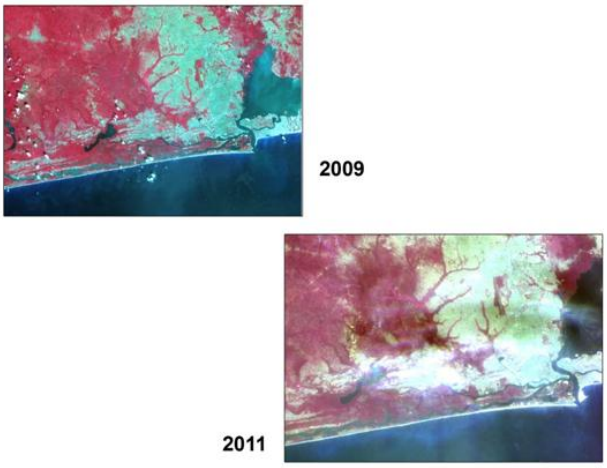

Fig. 2: Acquired RapidEye Satellite Image

4. Results and Discussions

4.1. Field spectral measurement

This study investigated the changes in the spectra from the reflectance measurements from wavelengths selected from the bands in the Visible, Red, RedEdge and NIR to the estimate the chlorophyll content of polluted and unpolluted vegetation. The measured spectra within 2 m radius had a total of 10 sample points per transect which were further averaged to have a representative measurement per transect (Table 1). Since each plot had 5 transect of measured spectra, the spectra were averaged in each plot to have a representative measurement per plot (Table 2). All these were done in the spectral library of ENVI 4.2 software. The reflectance measurements of healthy/unhealthy (stressed/unstressed) vegetation showed that the sensitivity of reflectance to vegetation stress is maximized within certain specified wavelength of spectral bands [15]. The result of the indices computation showed the varying level for which each index responded in the each plot and among plots.

Table 1: Spectral Indices Measurement for each Transect

PLOT A	NDVI	RVI	RedEdgeNDVI	VOG1	OSAVI
Transect 1	0.858088	13.09322	0.695275757	3.176258	1.185906
Transect 2	0.874336	14.91541	0.697968481	3.020727	1.236917
Transect 3	0.819157	10.05933	0.594210017	2.639596	1.115696
Transect 4	0.806473	9.334484	0.609451356	2.664003	1.095777
Transect 5	0.792811	8.653034	0.61852706	2.743725	1.053641
PLOT B					
Transect 1	0.831137	10.84389	0.682076936	3.103768	1.11913
Transect 2	0.808889	9.465122	0.634477076	2.817852	1.067645
Transect 3	0.748293	6.945734	0.604028668	2.714492	0.973807
Transect 4	0.860923	13.38049	0.63560214	2.700356	1.195991
Transect 5	0.823299	10.31853	0.593326032	2.593715	1.132303
PLOT C					
Transect 1	0.332456	1.996059	0.589095704	2.678967	1.113193
Transect 2	0.798456	8.923405	0.550770306	2.577058	1.089542
Transect 3	0.858888	13.1731	0.632083162	2.76138	1.190843
Transect 4	0.835686	11.17182	0.621456843	2.788952	1.148612
Transect 5	0.832138	10.91458	0.603325778	2.692556	1.138237
CONTROL					
Transect 1	0.875221	15.02836	0.707779408	2.945835	1.199275
Transect 2	0.838945	11.41812	0.652449478	2.781099	1.126647
Transect 3	0.881984	15.94686	0.692438693	2.9403	1.22459
Transect 4	0.885656	16.49114	0.718889087	3.08173	1.234341
Transect 5	0.863465	13.64825	0.699084038	2.900713	1.175251

(Source: Field Data 2012)

Table 2: The Spectral Indices Measurement for each plot

OGUN	NDVI	RVI	RedEdgeNDVI	VOG1	OSAVI
PLOT A	0.856765	12.96305	0.677158	2.952031	1.197078
PLOT B	0.812048	9.641019	0.632467	2.793848	1.091589
PLOT C	0.825401	10.45484	0.596376	2.690833	1.133354
CONTROL	0.873838	14.85268	0.69597	2.949498	1.203868

(Source: Field Data 2012)

The result showed variations in the spectral indicators most sensitive to chlorophyll content among the plots and the control in Ogun State. The variation in these indices could be attributed to the varying hydrocarbon spillage pollution levels. According to [16] noted that impacted vegetation usually respond to varying oiling stress, the extent of which depends on the severity of the oiling.

The spearman's rank correlation test was used to analyse the field indices data to determine the relationships between the spectral indices and the Chlorophyll content in the plots and the control. And the result showed that all the indices had some form of positive statistical correlation; however, only indices with correlation coefficients of 0.5 and higher were observed in plots B and C of Ogun state at $p>0.01$. The highest occurring spectral indices from the result of the Spearman's correlation (RedEdge and VOG1) were selected and used in the Analysis of Variance (ANOVA) to find out if there was any significant difference between less stressed and healthier vegetation or whether they were able to distinguish relatively healthy from relatively unhealthy vegetation. The result returned the best ratio that significantly differed between less stressed (control) and more stressed (impacted) plots. RedEdge indices was 4.564 at $p<0.01$ and 2.731 at $p<0.1$ for VOG1. The result showed variations in the spectral indicators most sensitive to chlorophyll content among the plots and the control in Ogun State. The variation in these indices could be attributed to the varying hydrocarbon spillage pollution levels.

4.2. Image spectral measurement

In analysing the RapidEye images of 5 m, only three vegetation indices NDVI, RVI and RedEdge were used for measurement computation. Table 3 shows the image measurement and revealed a general decline in the chlorophyll content from 2009 to 2011. Since there is a positive relationship between band indices and chlorophyll content, ANOVA was used to determine the relationship between the chlorophyll content and pollution level in the impacted plots. The result showed that there is a direct relationship between different pollution levels and the chlorophyll content which was statistically significant at $p<0.001$.

Table 3: Indices Measurement and Rate of Change from Image 2009 to Image 2011 within the Same Wavelength

PLOTS	RATE OF CHANGE FROM 2009 TO 2011		
	% change NDVI	% change RVI	% change RedEdge NDVI
PLOT A	-15.9707	-38.2769	-7.06669
PLOT B	-8.84564	-28.5856	-10.1613
PLOT C	-9.37896	-28.1117	-7.10855
CONTROL	-1.45285	-6.2659	-14.3669

(Source: RapidEye Image Data 2009, 2011)

4.3. Correlating in-situ and image data and the chlorophyll content

To correlate the field and image data, the field data was resampled by averaging intermediate points to match the satellite sensor bandwidth. The result is shown on Fig. 3.

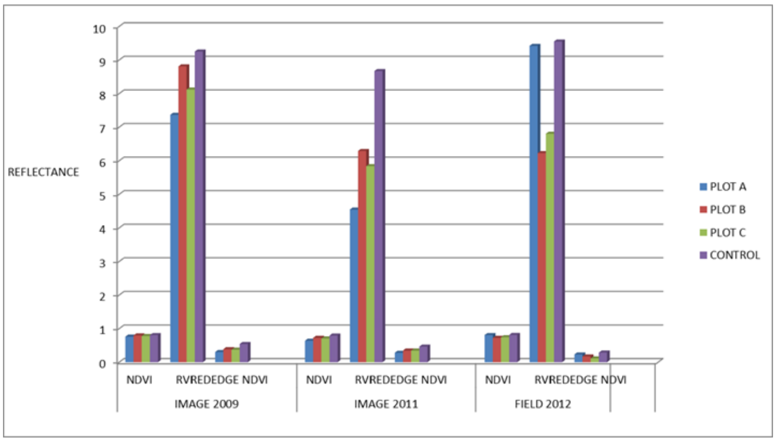

Fig. 3: Chart of the Three Indices of Image and Field Data

All measurements (field and image) were subjected to statistically analysis to test the correlation between the indices in the images data and the in-situ measurement; and to determine if there is a direct relationship between the image data of 2009 and 2011 and the field measurement of 2012. The result of the ANOVA showed that there is a direct relationship between in-situ measurement, image data and the chlorophyll content at the same wavelength which were statistically significant at $p<0.0001$ at of F-ratio 101.8 ($p < 0.0001$) for image 2009/field data and 48.65 ($p < 0.0001$) for image 2011/field data. This study revealed (from the rate of change) that hydrocarbon spillage affected the chlorophyll content of the vegetation at varying levels. Vegetation has different susceptibilities to contamination.

5. Conclusion

This study has shown that hydrocarbon spillage affected the spectra of vegetation by reliably measuring the reflectance spectrum changes that occur in the spectra of impacted vegetation and thus its health status determined. This study has also shown that Geo-information technologies are useful tools in assessing the impact of hydrocarbon pollution on the vegetation in Ogun State.

6. Acknowledgements

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