Semi – Automatic Detection and Monitoring of Surface Water Anomaly in Offshore Oil Mining Lease 59 in Nigeria

Chituru Dike Obowu¹, Tamunoene Kingdom Abam², Sabastine Ngah³

¹²³Institute of Geosciences and Space Technology, Rivers State University, Port Harcourt, Nigeria

Abstract— The OML 59 offshore environment in the Niger Delta is an active deltaic setting, physically and economically. It is exposed to a complex interaction of natural phenomena, oil and gas activities, fishing and navigational activities and these are potential sources of oil slicks and seeps. This work is primarily aimed at characterizing oil on water events and their association to oil and gas activities utilizing space synthetic aperture radar (SAR). The primary dataset being multi temporal Sentinel – 1A data acquired between 2015 and 2018. The analysis involved derivation of backscatter coefficients of the SAR images used, in order to identify dark regions. A novel approach applying gamma augmentation to the SAR datasets for the purpose of optimized characterization of the detected dark regions. Enhanced discrimination of dark regions using gamma, aided inference on the nature of weathering, thickness and behaviour of the detected oil anomaly. Geometric, textural and radiometric parameters of areas of detected anomalies were extracted and computed for the purpose of anomaly characterization. An anomaly confidence estimation algorithm was utilized, incorporating four key parameters in confidence estimation. These parameters are Homogeneity - uniformity in dark pixels of anomaly, Association - relationship of anomaly with a possible source, Signature - geometry of anomaly and contrast with respect to the ocean and Detectability - Ocean and satellite parameters such as wind speed and satellite incident angle. The quantitative extraction of these confidence estimating parameters was instrumental in the numerical computation of confidence levels using the HADS (Homogeneity Association Detectability Signature algorithm) computational method. Detected high confidence oil anomaly were strongly related to Otuo offshore oil and gas infrastructure, and these validated using optical satellite images: Landsat - 8 and Sentinel - 2. The results derived from this study establishes that SAR is a practical and effective tool in detecting oil on water within offshore oil mining leases, in addition to confirmation that oil spills occur as a result of oil and gas activities within this mining lease.

Keywords — Otuo; Backscatter; Dark Spot; Gamma; Image Processing; Oil Anomaly; SAR.

I. INTRODUCTION

The OML 59 offshore Gulf of Guinea marine environment hosts a prolific reserve of oil and gas and is the one of the near shore regions of oil and gas exploration and development activities in Nigeria. Due to the extensive volume of hydrocarbon development and navigational activities in this area there is high potential for release of crude oil and other pollutants into the environment. This can be through incidents and accidents such as oil well blowout, platforms leaking, bilge pumping by vessels and even through natural seepage from subsurface reservoirs. These can lead to pollution of the offshore environment, which negatively impacts the quality of the marine environment. It is believed that a larger percentage of oil release into the marine environment comes from industrial sources than from natural hydrocarbon seeps. Earth observation satellites such Synthetic Aperture Radar (SAR) provides several advantages over traditional approaches in detecting and monitoring oil-on-water in the marine environment. This is due to their relatively moderate cost and large area of coverage (Brekke and Solberg, 2005).

The characterization of backscatter from SAR images where dark spots have been detected and extracted is key to oil spill detection. Understanding the nature of these dark spots which represent potential oil on water anomalies is a challenge. The nature of SAR oil on water involves determination of the level of confidence assigned to a detected dark spot. The level of confidence is indicative of how sure an analyst is, in deciding if the dark spot is an oil on water event or a false positive. One key constituent in determining confidence is understanding the morphology of the dark spot backscatter values and relating them to the surrounding ocean clutter for areas without dark spots. This is usually done manually by an analyst, semi-automatically or fully automated using relevant processing software.

The primary objective of this study is to apply the use of Synthetic Aperture Radar (SAR) for the detection and monitoring of possible oil-on-water anomaly around Oil Mining Lease (OML) 59 in offshore Nigeria. This OML is host to subsea oil and gas wells in addition to other infrastructure such as platforms for the development of oil and gas. This is imperative as the occurrence of oil spill in the offshore environment has several impacts ranging from damage to the marine ecosystem to damage of the shore and inland ecosystem in cases where oil spill in the offshore hits the coast. Hence, the importance of early detection, monitoring and quantification of oil spills.
Post oil spill event management activities such as clean-up, remediation and compensation are also critical in restoring the environment and socio-economic life of the ecosystem impacted.

II. THE STUDY AREA

Location: OML 59 is a large oil mining block on the coastal swamp marginal of the Niger Delta. The license comprises the Otuo and Otuo South fields which were discovered by Elf in the 1970s. The fields were brought onstream by ConOil in 1999, which is an indigenous Nigerian company. Neighbouring this field is the small Obra field discovered in 2005, and the Ango discovered in 2013 and brought onstream in 2016. According to latest data from the Department of Petroleum Resources. It is geographic location that takes is bounded by Long 5.8663 Lat 4.3264 decimal degrees, Long 5.8863 Lat 4.3673 decimal degrees, Long 6.07 Lat 4.2783 decimal degrees and Long 6.0728 Lat 4.2231 decimal degrees.

Metoecean Setting: The OML 59 study area is located within a damp tropical setting with a climatic setting characteristic of relatively high humidity with an extended raining season spanning from March to October. The number of rainy days varies from 290-310 days with annual rainfall amount usually more than 3,000mm. Precipitation, in the comparatively dry periods, varieties from (22.8 to 97.7) mm while the wet periods varies between 125.3 to 464.9 mm. This area is peculiar in that it experiences the triple effect of tide, wave and current action, but is however wave dominated.

Waves: these are triggered by wind gusting over the water surface. The scale of waves is guided by how far, fast and for how long the wind is blowing. In the study area south westerly gusts prevail and are predominant in forte around April to September. Coastal winds also exist here and usually lie between 210-250° with an average speed of 10 knots. In this area, winds are weak in the beginning of July and gradually grow in strength between August and into part of September. The equivalent wave heights produced along the frontal sector of the fetch area have a period ranging between 2.8 and 6.5sec. It has been observed that it takes the lowest wave about five to eight days to reach the shoreline and vice-versa two to three days to reach the shoreline as swells. At the period of high spring tide, these swells could exceed 2.5m. Incidentally they also coincide with observed ocean surges.

Currents: these are unidirectional flow of water defined along the horizontal, and they constitute one of the primary parameters that have significant impact on weather in coastal areas.

This movement of water is triggered by several factors. These include:

1. Surface wind over water.
2. Salinity differentials related to evaporation, freshwater inflow and precipitation that cause thermohaline circulation.
3. Water temperature variations caused by irregular heating of the Earth's atmosphere by the Sun.
4. The Earth's rotation and associated Coriolis effect.

The currents affecting the study area of the offshore OML 59 study area consist mainly of longshore currents produced by waves that break south-west. A major factor in the long-term creation of beaches is the movement or drift of coastal sediments along a coastline, caused primarily by the motion of waves and tidal currents.

Tides: This is created by the phenomenon of upsurge and drop of sea stages, influenced by the combined impact of the force of gravity of the Moon and the Sun and the rotation of the Earth. These tides happen with a duration of about twelve hours and twenty minutes, and with an amplitude determined by sun and moon alignment and near-shore bottom shape. The study area exhibits two high and low tides each day with an average range value of 1.8m, with a slight variation in range.

III. DATA AND METHODOLOGY

Materials Used

The specialized resources used for processing, analysis and interpretation are images processing tools. SNAP toolbox software, ENVI Image processing software are used for Radar image processing and analysis, ranging from pre-processing to oil on water detection. While ESRI ArcGIS 9.0 (arcInfo license) for GIS spatial analysis and data integration.

Datasets Used

Radar Datasets -The data needed are acquired according to the research objectives are Sentinel – 1A SAR datasets acquired from 2015 to 2018, were downloaded from European Space Agency Copernicus Space Program. High resolution optical imagery from the Digital Globe constellation of satellites is obtained via Google Earth.
Satellite Derived Datasets

Marine Surface Temperature: The Global 1km Sea Surface Temperature (G1SST) global data is a key resource used for this study. G1SST utilizes datasets obtained from varying means such as, the highly reliable AVHRR, AATSR Scanning Radiometer, the Spinning Enhanced SEVIRI, the AMSRE EOS Microwave Radiometer, MODIS aqua, the GOES satellite Imager, the MTSAT – 1R multi-function radiometer, and in-situ datasets from drifting and moored buoys. This provides high resolution Marine surface temperature for detecting fronts, maximizes cloud free data including by including Geostationary data in its level 4 analysis.

Ocean Surface Wind Vectors: These datasets are daytime (descending) swaths of wind trajectories are calibrated at a 10m reference altitude overhead the ocean surface. These wind vectors are configured to point with the prevailing direction of the wind at the time of satellite pass. The data are provided from several instruments, amongst which are the ASCAT instrument flying on MetOp-A (sun – synchronous polar orbiter) at a 12.5km sampling resolution produced by the EUMETSAT Ocean and Sea ice Satellite Application Facility (OSI SAF) obtained through the Royal Netherlands Metrological Institute (KNMI) using Level 2 Climate Data Records (CDR) and the operational, near-real time (NRT) processed datasets that yield optimized coverage near coastal boundaries. These include layer time series data generated by the Level 2 CDR dataset. All data starting from 1st April 2014 and extending through the present day is generated by the operational NRT dataset. Providing high quality, high resolution wind vector data that allows once to see the wind direction and therefore assess the dynamics within the environment.

Radiometric Correction - Methodology

This involves calibration for purpose of generating radar datasets in which the pixel values can be directly related to the radar backscatter of the scene. This involves undoing the processor applied image output scaling and the desired scaling reintroduced. The Sentinel-1A Level-1 product used provide four calibration LUTs to produce β0i, σ0i and γ0i (Beta, Sigma and Gamma nought) or to return to the Digital Number (DN).

The LUTs apply a range-dependent gain including the absolute calibration constant. For ground range products a constant offset is also applied.

The radiometric calibration is applied by the following equation:

\[
\text{value}(i) = \frac{[\text{DN}]^2}{A_i} \quad (1)
\]

where, depending on the selected LUT,

- value(i) = one of β0i, σ0i or γi or original DNi
- Ai – one of betaNought(i), sigmaNought, gamma(i) or dn(i)

Bi-linear interpolation is used for any pixels that fall between points in the LUT

Speckle Noise Removal - Methodology

A typical SAR image is a mean intensity estimate of the radar reflectivity of the region which is being imaged. Speckle noise in SAR is the difference between a measurement and the true mean value of the Radar signal. This is removed through the application of filters to the radar signal.

Lee Filter: assumes that the mean and variance of the pixel of interest is equal to the local mean and variance of all pixels within the user-selected moving kernel. TheLee filter calculation produces an output value close to the original input value in higher contrast regions and a value close to the local mean for uniform areas. In the latter case a stronger smoothing occurs. The formula for the Lee filter is the following:

\[
\text{Where } \text{DN}_{\text{out}} = \text{[Mean]} + K[\text{DN}_{\text{in}} – \text{Mean}] \quad (2)
\]

\[
\text{Mean} = \text{average of pixels in a moving window}
\]

\[
K = \frac{\text{Var}(x)/[(\text{Mean})^2 \sigma^2 + \text{Var}(x)]} \quad (3)
\]

\[
\text{Var}(x) = \frac{[(\text{Variance within window}) + (\text{Mean within window})^2]/(\text{Var}(\Sigma)^2 +1[)] – [\text{Mean within window}]^2} \quad (4)
\]

Discontinuity Adaptive Prior and Moment Estimation algorithm is to be used to reduce speckle noise SAR images. The stepwise algorithm is as given below:

1) Do the modelling of the original image f(m,n) with probability density function

\[
p(f(m,n)/f^\wedge(x,y)) = e^{x^\wedge(-\log(1+\eta^2(f(m,n),e^{x\wedge(-\log(1+\eta^2(f(m,n),f^\wedge(\text{m-x,n-y})))))})\}
\]

where, \(\eta^2(f(m,n),f^\wedge = (1/p)^2 \sum(x,y) (f(m,n) - f^\wedge(m-x,n-y))^2\)

(x,y)ε {(0,1),(1,0),(1,1),(1,-1)}
2) Do the estimation of mean μ and variance σ² using the mathematical model

\[ \text{Infinity } \infty \text{ is the samples drawn from the sampler PDF “q” which concentrate on the points where } p \geq q. \text{ When } q \geq p, \text{ we can use samples from } q \text{ to determine estimation under } p. \]

3) Incorporate the observed noise model as;

\[ X(m,n)/(m,n - 1) = [\mu, 1]^T \text{ and } P(m,n)/(m,n - 1) = [\alpha^2]. \quad (6) \]

4) Calculate sigma points as; \[ Y(m,n)/(m,n-1) = X(m,n)/(m,n-1)* (m,n-1) \quad (7) \]

5) Apply the measurement model on each sigma point.

**DN to dB Conversion - Methodology**

In order to classify water bodies for oil on water detection and get results in terms of better contrasts, it is imperative to convert the data DN values to Sigma0 dB. Sigma dB is in a logarithmic scale and this enhances the contrast between features and hence improve anomaly detectability.

Radar image brightness is expressed in \( \sigma_0 \) (sigma naught) which is the radar backscatter per unit area. The unit of \( \sigma_0 \) is \([m^2/m^2]\), expressed in decibel (dB). The standard formula to calculate \( \sigma_0 \) is:

\[ \sigma_0 = 10 \times \log_{10}(DN^2) + K \quad (8) \]

Where, DN is the image pixel digital number measured in the SAR image. K is a calibration factor which varies depending on the SAR sensor and processor system used.

Where, \( \sigma_0 \) (dB) – backscattering image in dB
\( \sigma_0 \) – Sigma naught image.

For homogeneous targets, \( \sigma_0 \) varies slightly depending on the incidence angle – being higher (brighter) in the near-range part of the image (closest to the satellite) and lower (darker) in the far-range of the image, further away from the satellite. By normalising \( \sigma_0 \) with respect to the incidence angle we can remove the range-dependency to obtain \( \gamma_0 \) (gamma-naught):

\[ \gamma_0 = \sigma_0/\cos\phi \]

where \( \phi \) is the incidence angle.

**Land - Sea Masking - Methodology**

The land/sea mask by default uses the SRTM DEM to quickly give a rough mask to remove the land or sea. It’s intended for the ocean with coasts (such as the offshore OML 59) where there is limited availability of local high accuracy DEMs and a rough estimate of elevations is good enough. The SRTM of course does not include any information about inland water bodies.

The fractional land/water mask uses 50m shoreline data and can be more precise along the coast.

**Dark Spot Detection Adaptive Threshold - Methodology**

This is the simplest image segmentation method, and in the thresholding process a threshold value is first set according to defined rules. Pixels are then partitioned into “objects” and “background” according to the threshold. An adaptive thresholding method on the image generates dark spots which are potential anomalies. A detecting window is moving through the whole image. The threshold is calculated locally, within the area of a moving window, which is set for dark spots as \( \Delta dBk \) below the mean value in a moving window. The value of \( \Delta dBk \) is calculated by the ratio of the standard deviation to the mean value in the local window. The thresholding is combined with a multi-scale approach and a clustering step to effectively separate dark spots from background. Though the thresholding method can achieve fast detecting speed, it may also lead to many false alarms in the process because of speckle noises. Post-processing, such as clustering is usually necessary to eliminate these detected false alarms.

**Backscattering Coefficient Analysis - Methodology**

The Sentinel-1A radar return scattering coefficient values is evaluated as follows:

\[ \sigma_0(dB) = \beta_0(dB) + 10 \log_{10}(\sin(ip)/\sin(ic)) \]

\[ \sigma_0(dB) = 20 \log_{10}(DN) - K \text{ (dB)} \]

Where, \( \beta_0 \) (dB) = 20log10(DN) - K (dB)
\( ip= \text{ angle of incidence for a particular pixel} \)
\( ic= \text{ angle of incidence for center of the image} \)
\( K = \text{ calibration constant of SAR image} \)

A total number of 11 images were used in this analysis. The images were converted from amplitude DN values to linear dB power values in order to the used for oil on water analysis.

**Gamma Enhancement - Methodology**

In order to improve visualization and discrimination of the tonal variation in detected dark spots Gamma correction is applied to the processed SAR data. This defines the relationship between a pixel’s numerical value and its actual luminance. Gamma artificially increases the image tonal data values in a SAR image. It smooths image data, without removing edges or sharp features in the images and preserves the observed pixel value for non-Gamma-distributed images. The Gamma enhancement minimizes the loss of texture information since it uses the statistical properties of the underlying image.
Assuming a Gamma-distributed image, the resulting grey-level value \( R \) for the smoothed pixel is \( \text{(Copyright © PCI Geomatics, 2018)} \):

\[
R = \text{Im} \text{ for } Ci \leq Cu \\
R = Rf \text{ for } Cu < Ci < C_{\text{max}} \\
R = Ic \text{ for } Ci \geq C_{\text{max}}
\]

where:

\[
Rf = \frac{(B*\text{Im} + \sqrt{D})}{2*A} \\
Ci = \frac{S}{\text{Im}} \\
Cu = \sqrt{\frac{1}{\text{Number of Looks}}} \\
C_{\text{max}} = \sqrt{2} \times Cu \\
\text{Im} = \text{mean value of intensity within the kernel} \\
S = \text{standard deviation of intensity within the kernel} \\
Ic = \text{center pixel in the kernel} \\
A = \frac{(1+Cu^2)/(Ci^2 - Cu^2)}{\text{Number of Looks}-1} \\
B = A - \text{Number of Looks} - 1 \\
D = \text{Im}^2*B*B + 4*A*\text{Number of Looks}^2*\text{Im}*Ic
\]

The relationship between the input and output is that the output is proportional to the input raised to the power of gamma. The formula for calculating the resulting output is as follows:

\[I' = 255 \times (\frac{1}{255})^y \quad (9)\]

Below is representative of a pseudo-code performing gamma correction:

\[
\text{gammaCorrection} = 1 / \text{gamma} \\
\text{colour} = \text{GetPixelColour(x, y)} \\
\text{newRed} = 255 \times (\text{Red(colour)} / 255)^\text{gammaCorrection} \\
\text{newGreen} = 255 \times (\text{Green(colour)} / 255)^\text{gammaCorrection} \\
\text{newBlue} = 255 \times (\text{Blue(colour)} / 255)^\text{gammaCorrection} \\
\text{PutPixelColour(x, y)} = \text{RGB(newRed, newGreen, newBlue)}
\]

**Anomaly Characterization**

The key characteristics in interpreting anomalies are:

**Shape:** Given the vast area and differing conditions on one image, slicks often stand out because of their shape as they are, generally, not part of the natural environment. Natural oil seeps can ‘blend’ into the scene dynamics, while non-natural oil releases tend to be more distinct, usually have 2 basic presentations:

1. Long, thin and linear (discharge from moving vessel)
2. Various sizes – but regular shape, and emanating from a point source (discharge from oil production facility or stationary vessel)

They can be Linear, Plume, Pear or oval, Comb, Horse Shoe, Irregular or Feathering.

**Size:** Knowledge of area (ideally gained through local experience, or from repeated observations) will give an indication of the types of oil present in the region, and hence the likely size of such events. An example is a ship source (moving) oil release typically in the 100’s to 1000’s of meters in width and can be extremely long (over 100km). Platform releases tend to be smaller, possibly 10’s of kilometers in size, various widths (can be linear or circular).

**Contrast:** In otherwise homogeneous environment, the most obvious detection of a potential anomaly is depicted by large contrast from surrounding ‘grey levels’ in the area around the potential oil. Contrast is based on a multitude of factors and this makes the creation of “signature” libraries based solely on contrast very difficult (and hence, makes automation even more of a challenge). Over time the contrast will become less due to several phenomena such as weathering, biodegradation and evaporation which break down the slick. Thickness, oil type and concentration also play a key role in slick appearance and this is very difficult to quantify. Near-range/far-range location of slick in the image – near-range slicks should appear darker than far range

**Context:** This is probably the most powerful determinant of the confidence of the analysis. The situation in the surrounding environment / conditions in the area, have a large influence on interpretation. Details of the slick edge can add a time element (start-end of slick), and when coupled with wind direction provide morphology information. Targets in the area of a potential slick are also significant pointers, and in some situations, erroneously ‘force’ decision. The presence of other oil-like signatures in proximity to a potential spill source is a positive indicator.
Geometric Analysis

The following parameters are of importance is characterizing a possible oil anomaly:

a) Spread ($S$): this is usually expressed as low values in small and linear features and larger values for more spherical features. As defined from Del Frate et al. (2000) the eigenvalues derived from the eigenvalue decomposition of the principal component analysis (PCA) vectors of the dark objects is taken as $\lambda_1$ and $\lambda_2$, then oil spread is represented as:

$$S=100\frac{\lambda_1}{(2\lambda_1+\lambda_2)}$$  \hspace{1cm} (10)

b) Area of oil anomaly ($A$) [in km$^2$]: this refers to the number of picture elements multiplied by the picture element spacing of the whole image dataset.

c) Aspect ratio of oil anomaly ($AR$): This is usually expressed as small values for linearized features and high for more asymmetrical and irregular shapes. This is the fraction of the minor and major axis obtained from the PCA.

d) Oil anomaly width [in km]: With assumption of uniform width, it is the minor axis of the PCA.

e) Oil anomaly length [in km]: this is the PCA derived major axis.

f) Perimeter of oil anomaly ($P$) [in km]: the total perimeter of pixels outlines of the possible anomaly.

g) Oil anomaly Complexity ($C$): this characterizes the geometric complexity of the dark target. It’s characterized by minor values for features with modest geometry and larger values for features with more complexity. It is described from Del Frate et al. (2000) as

$$C=P/2\pi A$$  \hspace{1cm} (11)

When, $P$ and $A$ are the Perimeter and Area respectively

h) Center of Mass of oil anomaly [in pixels]: obtained from the eigen values of the principal component analysis. This is valuable to obtain the distance and position between targets.

Textural Analysis

The ability to highlight and characterize texture is one of the unique qualities of SAR. The following parameters are of importance is characterizing a possible oil anomaly as calculated from backscatter values of the SAR image:

a) Object/Target Power to Mean Ratio ($OPMR$): is represented as OSD / OMEAN of a possible anomaly. When PMR values are high this is indicative of low wind zones and hence high contrast between anomaly and surroundings is expected (Solberg et al. 2007).

b) Background/Ocean Power to Mean ratio ($BPMR$): is BSD/BMEAN

Confidence Estimation

A confidence estimation scheme was designed to classify the level of certainty in a detected oil on water anomaly. This level is categorized into very high, high, moderate and low confidence. In order to compute confidence levels a number of geometric, radiometric, textural properties, locational and metocean conditions characteristic is the anomaly is analyzed. Specifically, the anomalies are analyzed with respect to Homogeneity - uniformity of dark Pixels based on extracted dB values, Association – strength of relationship with a potential source, Signature - geometry of the and contrast with the surrounding ocean, Detectability - Ocean/Satellite Parameters such as wind speed and satellite incident angle and how well they support oil detection. This work will introduce a fully quantitative estimation of anomaly confidence level through the development of the HADS algorithm (Homogeneity-Association-Detectability-Signature). This eliminate the use of subjectivity in estimating confidence levels as done in most SAR analysis. HADS computes confidence based on quantitative data and defined set of rules when analyzing homogeneity, association, detectability and signature related to a detected anomaly. The HADS parameters are categorized based on boundary conditions and are represented below:

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>KEY PARAMETERS FOR CONFIDENCE ESTIMATION USING SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Unit</td>
</tr>
<tr>
<td>Homogeneity</td>
<td>Power (db)</td>
</tr>
<tr>
<td>Low</td>
<td>16.24 - 17.73</td>
</tr>
<tr>
<td>Moderate</td>
<td>14.75 - 16.23</td>
</tr>
<tr>
<td>High</td>
<td>0 - 14.74</td>
</tr>
<tr>
<td>Association</td>
<td>Distance (km)</td>
</tr>
<tr>
<td>High</td>
<td>0 - 0.2</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.2 - 1</td>
</tr>
<tr>
<td>Low</td>
<td>&gt; 1</td>
</tr>
<tr>
<td>Signature</td>
<td>Measure of Linearity/Curvature</td>
</tr>
<tr>
<td>Linear/Curved/Distinct edges</td>
<td>Strong</td>
</tr>
<tr>
<td>Linear/Curved/Feathered edges</td>
<td>Moderate</td>
</tr>
<tr>
<td>Irregular/Random/Feathered edges</td>
<td>Weak</td>
</tr>
<tr>
<td>Detectability</td>
<td>Wind Speed (m/s)</td>
</tr>
<tr>
<td>High</td>
<td>3 - 12.9</td>
</tr>
<tr>
<td>Moderate</td>
<td>2.5 - 2.99 and 12.9 - 13</td>
</tr>
<tr>
<td>Low</td>
<td>&lt; 2.8 and &gt; 12.8</td>
</tr>
</tbody>
</table>
Each of the 4 confidence parameters are assigned a maximum percentage score of 25%. The formula below computes the confidence level of each anomaly:

\[
\text{Anomaly Confidence Level (\%) = H + A + D + S}
\]  

(12)

Where H = Homogeneity, A = Association, D = Detectability, S = Signature

and,

Very High Confidence (\%) = 100
High Confidence (\%) = 60.1 - 99
Moderate Confidence (\%) = 25.1 - 60
Low Confidence (\%) = 0 - 25

Very High & High Confidence: The slick has a large contrast to the surroundings. The surroundings are homogeneous. The wind speed is moderate to high, i.e. approximately 6-10 m/s. Ship or oil installation is directly connected to the anomaly.

Moderate confidence: The wind speed is moderate to low, i.e. approximately 3-6 m/s. The detected anomaly has a diffuse/low contrast to the gray level surrounding in moderate to high wind speeds. The shape of the anomaly is irregular, i.e. the edges are not smooth.

Low confidence: Low wind areas persist in the area. Natural slicks (e.g. algae bloom) are in proximity to the anomaly. The anomaly has diffuse edges and/or an irregular shape. All the different aspects are assessed together and against each other to determine the confidence level. All results will have some degree of uncertainty in them, and experienced operators are an important factor.

IV. EXPERIMENTAL RESULT

Backscattering Coefficient and Gamma Augmentation: The dB values were also represented in a logarithmic scale due to the scale of the data values and the need to adequately represent them for evaluation and analysis. Transects were drawn to traverse areas with potential oil on water events and the dB values extracted. These backscatter data are the fundamental dataset in which oil on water analysis is based.

<table>
<thead>
<tr>
<th>Image Name</th>
<th>Anomaly Type</th>
<th>Probable Source</th>
<th>Location</th>
<th>Ocean dB_mean</th>
<th>Oil dB_mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1A_IW_GRDH_1SDV_20150703T175237_20150703T175306_006650_008E07_CC55</td>
<td>Oil</td>
<td>Otuo -1</td>
<td>Otuo field</td>
<td>19.00568793</td>
<td>17.0433605</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150808T175239_20150808T175308_007175_009CC6_BC84</td>
<td>Oil</td>
<td>Otuo -1</td>
<td>Otuo field</td>
<td>18.57619456</td>
<td>15.42592205</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150820T175239_20150820T175308_007350_00A185_8283</td>
<td>Oil</td>
<td>Otuo -1</td>
<td>Otuo field</td>
<td>19.48387545</td>
<td>16.765375</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150901T175240_20150901T175309_007525_00A650_4DBD</td>
<td>Oil</td>
<td>Otuo -1</td>
<td>Otuo field</td>
<td>19.18003172</td>
<td>17.2151302</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150925T175241_20150925T175310_007875_00AFAE_5511</td>
<td>Oil</td>
<td>Otuo -1</td>
<td>Otuo field</td>
<td>18.8600265</td>
<td>16.89773559</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20151111T175235_20151111T175304_008575_00C287_44E3</td>
<td>Oil</td>
<td>Otuo -1</td>
<td>Otuo field</td>
<td>18.11656398</td>
<td>15.6196542</td>
</tr>
</tbody>
</table>

The dB and Gamma give the indication of a long period of slow, steady and continuous discharge of oil into the ocean as there is evidence of weathering, feathering and heterogeneity in the observable oil on water event. Gamma enhancement of between 1.9 – 2.05 was applied on the SAR power converted datasets which have identified anomalies.

This increased contrast level of the backscatter values enhanced the extraction of the geometric and radiometric properties of the identified anomalies these discriminating their fate, extent of weathering, qualitative thickness, morphology and size.
Figure 1. Transect dB data and gamma image showing oil-on-water anomaly around Otuo Platform (3rd July 2015)

Figure 2. Transect dB data and gamma image showing oil-on-water anomaly around Otuo Platform (8th August 2015).
Figure 3. Transect dB data and gamma image showing oil-on-water anomaly around Otuo Platform (20th August 2015).

Figure 4. Transect dB data and gamma image showing oil-on-water anomaly around Otuo Platform (1st September 2015).
Figure 5. Transect dB data and Gamma image showing Oil-on-Water Anomaly around Otuo Platform (25th September 2015).

Figure 6. Transect dB data and Gamma image showing oil-on-water anomaly around Otuo Platform (12th November 2015).
Figure 7. Transect dB data and gamma image showing oil-on-water anomaly around Otuo Platform (30th December 2015).

Figure 8. Transect dB data and gamma image showing oil-on-water anomaly around Otuo Platform (11th January 2016).
Figure 9. Transect dB data and gamma image showing oil on water anomaly around Otuo platform (5th January 2017)

Geometric and Textural Analysis

Complex anomalies identified were related to multiple sources such as the anomaly of 29th January 2017. This is probably related to oil discharge from Otuo platform and a passing vessel engaging in bilge dumping.

Table 3

<table>
<thead>
<tr>
<th>S/N</th>
<th>Image Name</th>
<th>Probable Source</th>
<th>Location</th>
<th>Perimeter (km)</th>
<th>Area (km²)</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1A_IW_GRDH_1SDV_20150703T175237_20150703T175306_006650_006E07_CC55</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>4.27</td>
<td>0.84</td>
<td>2.329</td>
</tr>
<tr>
<td>2</td>
<td>S1A_IW_GRDH_1SDV_20150808T175239_20150808T175308_007175_009CC6_BC84</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>7.89</td>
<td>1.67</td>
<td>3.053</td>
</tr>
<tr>
<td>3</td>
<td>S1A_IW_GRDH_1SDV_20150820T175239_20150820T175308_007350_00A185_8283</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>3.85</td>
<td>0.33</td>
<td>3.351</td>
</tr>
<tr>
<td>4</td>
<td>S1A_IW_GRDH_1SDV_20150901T175240_20150901T175309_007525_00A650_4DBD</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>4.41</td>
<td>0.83</td>
<td>2.42</td>
</tr>
<tr>
<td>5</td>
<td>S1A_IW_GRDH_1SDV_20150925T175241_20150925T175310_007875_00AFAE_5511</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>4.41</td>
<td>1.22</td>
<td>1.996</td>
</tr>
<tr>
<td>6</td>
<td>S1A_IW_GRDH_1SDV_20151112T175235_20151112T175304_008575_00C287_44E3</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>13.63</td>
<td>5.14</td>
<td>3.006</td>
</tr>
<tr>
<td>7</td>
<td>S1A_IW_GRDH_1SDV_20151230T175234_20151230T175303_009275_00D634_D21F</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>12.36</td>
<td>2.6</td>
<td>3.833</td>
</tr>
<tr>
<td>8</td>
<td>S1A_IW_GRDH_1SDV_20160111T175233_20160111T175302_009450_00DB31_CC93</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>7.5</td>
<td>3.14</td>
<td>2.116</td>
</tr>
<tr>
<td>9</td>
<td>S1A_IW_GRDH_1SDV_20160814T175243_20160814T175312_012600_013C0F_CF19</td>
<td>CONTROL</td>
<td>Otuo field</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>10</td>
<td>S1A_IW_GRDH_1SDV_20170105T175242_20170105T175311_014700_017EAF_270C</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>15.96</td>
<td>5.22</td>
<td>3.493</td>
</tr>
<tr>
<td>11</td>
<td>S1A_IW_GRDH_1SDV_20170129T175241_20170129T175310_015050_018977_5247</td>
<td>Otuo Platform, Ship</td>
<td>Otuo-1 field</td>
<td>56.47</td>
<td>7.79</td>
<td>10.116</td>
</tr>
</tbody>
</table>

Anomalies around Otuo platform of 18th November 2016 generally displayed simple geometry, characteristic of small, but continuous discharge of oil from a point source.
**TABLE 4**

**SENTINEL – 1A IMAGES USED AND KEY COMPUTED TEXTURAL PARAMETERS**

<table>
<thead>
<tr>
<th>Image name</th>
<th>Anomaly Type</th>
<th>Probable Source</th>
<th>Location</th>
<th>BMEAN</th>
<th>OMEAN</th>
<th>OSD</th>
<th>OPMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1A_IW_GRDH_1SDV_20150703T175237_20150703T175306_006E050_008E07_CC55</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>19.01</td>
<td>17.04</td>
<td>0.419</td>
<td>0.0246</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150808T175239_20150808T175308_007175_009CC6_BC84</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>18.58</td>
<td>15.43</td>
<td>0.701</td>
<td>0.0455</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150820T175239_20150820T175308_007350_00A185_8283</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>19.48</td>
<td>16.77</td>
<td>0.549</td>
<td>0.0328</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150901T175240_20150901T175309_007525_00A650_4DBD</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>19.18</td>
<td>17.22</td>
<td>0.322</td>
<td>0.0187</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150925T175241_20150925T175310_007875_00AFAE_5511</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>18.86</td>
<td>15.51</td>
<td>0.6688</td>
<td>0.0431</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20151112T175235_20151112T175304_008575_00C287_44E3</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>18.12</td>
<td>15.62</td>
<td>0.621</td>
<td>0.0398</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20151230T175234_20151230T175303_009275_00D634_D21F</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>18.15</td>
<td>16.22</td>
<td>0.5064</td>
<td>0.0312</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20160111T175233_20160111T175302_009450_00DB31_CC93</td>
<td>Control</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>18.95</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20170129T175241_20170129T175310_015050_018977_5247</td>
<td>Oil</td>
<td>Otuo Platform,</td>
<td>Otuo field</td>
<td>18.34</td>
<td>17.03</td>
<td>0.4287</td>
<td>0.0252</td>
</tr>
<tr>
<td></td>
<td>Ship</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Control - Anomaly Analysis**

A times series design process was employed in analysis of images with detected anomaly vis-a-vis a control image without any detected anomaly. The control image acquisition conditions and analysis methodology closely mirror that of the images having detected anomaly. This method is employed since it cannot fully manipulate the variable such as metocean conditions, atmospheric conditions and exact satellite acquisition parameters. However, the variation in these parameters is very minimal in order to affect the nature of the post test. This is so, as only images with negligible variation in parameters were selected for the test. This was done for anomaly around Otuo Platform.

Transects were drawn to traverse regions within the post-test images with detected anomaly, and the dB values of the dark region pixels extracted. The same transects were used to extract dB values of the pixels in the pre-test image (control) without detected anomaly. The control images showed a clear pattern of significantly higher dB values along the transect lines.

**TABLE 5**

**CONTROL VS. OIL ANOMALY DATA OF IMAGE PARAMETERS AND OBJECT CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Image Name</th>
<th>Anomaly Type</th>
<th>Probable Source</th>
<th>Location</th>
<th>BMEAN</th>
<th>OMEAN</th>
<th>OSD</th>
<th>OPMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1A_IW_GRDH_1SDV_20150703T175237_20150703T175306_006E050_008E07_CC55</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>19.01</td>
<td>17.04</td>
<td>0.419</td>
<td>0.0246</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150808T175239_20150808T175308_007175_009CC6_BC84</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>18.58</td>
<td>15.43</td>
<td>0.701</td>
<td>0.0455</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150820T175239_20150820T175308_007350_00A185_8283</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>19.48</td>
<td>16.77</td>
<td>0.549</td>
<td>0.0328</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150901T175240_20150901T175309_007525_00A650_4DBD</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>19.18</td>
<td>17.22</td>
<td>0.322</td>
<td>0.0187</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20150925T175241_20150925T175310_007875_00AFAE_5511</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>18.86</td>
<td>15.51</td>
<td>0.6688</td>
<td>0.0431</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20151112T175235_20151112T175304_008575_00C287_44E3</td>
<td>Oil</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>18.12</td>
<td>16.22</td>
<td>0.5064</td>
<td>0.0312</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20160111T175233_20160111T175302_009450_00DB31_CC93</td>
<td>Control</td>
<td>Otuo Platform</td>
<td>Otuo field</td>
<td>18.95</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>S1A_IW_GRDH_1SDV_20170129T175241_20170129T175310_015050_018977_5247</td>
<td>Oil</td>
<td>Otuo Platform,</td>
<td>Otuo field</td>
<td>18.34</td>
<td>17.03</td>
<td>0.4287</td>
<td>0.0252</td>
</tr>
<tr>
<td></td>
<td>Ship</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Straight lines of best fit were drawn to establish a distinct pattern of dB backscatter values in images with detected anomalies. This highlights that within an area of detected time series of oil on water events, the dB values are generally of the same pattern and significantly lower than on an image of the same around but without detected anomaly.
Confidence Estimation

The estimation of the confidence level of a detected anomaly is key to the determination of true oil spills/slicks and oil look-a-likes. This involves running a confidence algorithm which incorporates geometric, textural and radiometric characteristics along with positional information of potential spill source and metocean forces at play within the period of image acquisition. Quantitative extraction of these confidence estimating parameters was instrumental in the numerical computation of confidence levels using the HADS (Homogeneity Association Detectability Signature algorithm) computational method developed from this study proved quite reliable.

All the images used for analysis are high on detectability as the wind conditions at their times of image acquisition are within the optimal windspeed threshold of 2.5m/s - 2.99m/s and 12.9m/s – 13m/s as elaborated by Brekke (2007). Hence, a full score of 25% for detectability for all SAR images used. Otuo platform oil events are high on association due to the proximity of the detected anomaly to a potential source. Hence a full score of 25% on the parameter of Association. Analysis of Homogeneity and Signature variation of images from Table 4.7 reveals a general pattern of images with high homogeneity also having a strong signature consistent with a high potential positive oil on water anomaly as indicated by ESA 2015.

In the Homogeneity – Association – Detectability – Signature algorithm (HADS), a categorization of the estimated confidence attributable to each anomaly detection is carried out based on the classes below:

- **Probable Anomaly (High Confidence):** 66% – 100% Score in HADS algorithm
- **Possible Anomaly (Moderate Confidence):** 33% – 66% Score in HADS algorithm
- **Like Anomaly (Low Confidence):** 0% – 33% Score in HADS algorithm

This classification produced similar results as in ESA/KSAT more subjective confidence estimation method.

Control location used for analysis in Otuo platform event was analyzed and the confidence detection level attributed to them was Likely (low). This is so as there was no detectable anomaly in the control images All detected events were Probable (high) confidence due to their proximity to a potential source, textural, radiometric, geometric properties and excellent metocean conditions at image acquisition time. These anomalies also exhibited the characteristic signature of human activity induced oil on water in the ocean.

### Table 6

**CONFIDENCE PARAMETERS AND ESTIMATION OF DETECTED ANOMALIES**

<table>
<thead>
<tr>
<th>Scene Name</th>
<th>Homogeneity</th>
<th>Association</th>
<th>Signature</th>
<th>Detectability</th>
<th>Score (%)</th>
<th>Detection Parameters</th>
<th>Score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20150716T5255 Otuo Platform</td>
<td>16.6</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>91.6</td>
<td>Homogeneity: Uniformity of Dark Pixels</td>
<td>100</td>
</tr>
<tr>
<td>20151230T5229 Otuo Platform</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>100</td>
<td>Association: Relationship with Source</td>
<td>66 - 100</td>
</tr>
<tr>
<td>20160409T5250 Otuo Platform</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>100</td>
<td>Signature: Geometry and Contrast</td>
<td>33 - 66</td>
</tr>
<tr>
<td>20160921T5224 Otuo Platform</td>
<td>16.6</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>91.6</td>
<td>Detectability: Ocean/Satellite Parameters</td>
<td>100</td>
</tr>
<tr>
<td>20161027T5221 Otuo Platform</td>
<td>16.6</td>
<td>25</td>
<td>16.6</td>
<td>0</td>
<td>58.2</td>
<td>Wind Speed (m/s)</td>
<td>Moderate</td>
</tr>
<tr>
<td>20151112T5226 Otuo Platform</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>100</td>
<td>Detectability</td>
<td>2.5 - 2.9 and 12.9 - 13</td>
</tr>
<tr>
<td>20151230T5224 Otuo Platform</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>100</td>
<td>High</td>
<td>0</td>
</tr>
<tr>
<td>20160409T5225 Otuo Platform</td>
<td>16.6</td>
<td>25</td>
<td>16.6</td>
<td>25</td>
<td>83.2</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>20151005 Otuo Platform</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>25</td>
<td>83.3</td>
<td>Like Anomaly (Low Confidence)</td>
<td>Score (%)</td>
</tr>
</tbody>
</table>

**Homogeneity**

<table>
<thead>
<tr>
<th>Score (%)</th>
<th>Association</th>
<th>Distance (km)</th>
<th>Score (%)</th>
<th>Signature</th>
<th>Linearity/Curvature</th>
<th>Score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>0 - 14.74</td>
<td>25</td>
<td>High</td>
<td>0 - 0.2</td>
<td>Curvilinear/distinct</td>
<td>25</td>
</tr>
<tr>
<td>Moderate</td>
<td>14.75 - 16.23</td>
<td>16.6</td>
<td>Moderate</td>
<td>0.2 - 1</td>
<td>Curvilinear/feathered</td>
<td>Moderate</td>
</tr>
<tr>
<td>Low</td>
<td>16.24 - 17.73</td>
<td>8.3</td>
<td>Low</td>
<td>&gt; 1</td>
<td>Irregular/feathered edges</td>
<td>Weak</td>
</tr>
</tbody>
</table>
Validation of Results

Optical Satellite Imagery Validation: Optical imagery was acquired and processed into natural colour composites with atmospheric removal for band combination RGB 754 and natural colour composite RGB band combination 432 for Landsat-8 and Sentinel-2 respectively. These optical images highlighted clearly observable oil on water events around Otuo Platform.

Figure 12 Oil anomaly identified around Otuo platform in Landsat-8 imagery acquired on 15/01/2015.

Figure 13. Oil Anomaly identified around Otuo platform in Sentinel-2 imagery acquired on 03/01/2018.
V. CONCLUSION

This work was able to demonstrate the use of space-based imaging in the detection, monitoring and correlation of oil on water events to an offshore oil and gas production infrastructure. Gamma augmentation and backscatter coefficient analysis help in surface oil spill detection by extending the contrast spectral range of the detected anomaly. This is instrumental in revealing the degree of homogeneity, level of weathering, fate and the geometry of detected anomaly around the oil spills observed with the OML 59. Utilizing control data and HADS anomaly confidence analysis algorithm, it was able to categorize the different anomaly detection into confidence levels. The confidence in the analysis was further strengthened after validation that oil spill events are associated with the Otuo platform using optical imagery. There was significantly close correlation between information on texture, geometry observed between optical satellite imagery of the spill and processed SAR data.

There is however more scope for future work for improving interpretation of SAR datasets using more filters, stretch methodologies and more advanced algorithms. The Oil and gas industry, NGOs, governmental agencies and the academia in Nigeria can harness the existing SAR data, methodologies and expertise to strengthen the detection, monitoring and response to oil spill in Nigeria and the Gulf of Guinea.

REFERENCES