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Modelling and Mapping Oil Pollution across the Inland and Coastal Waters: A Case of Selected Segment of Gulf of Guinea

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ABSTRACT: *Artisanal fisheries in the Niger Delta and Nigeria's coastal waters support the livelihood of its inhabitants, thus management of water pollution has public health significance for the regions and beyond. Oil Spills and contaminated runoff from the hinterland always find their way to the coast via the extensive network of rivers and creeks across the delta. This is a major cause of marine pollution in the region. With this understanding there is a need to map and model the dynamics of oil pollution across the coastal waters of the Niger Delta, thereby providing evidence and data support for their management. This study explored the potential of mapping oil slicks along the inland and coastal water of the Niger Delta using the SENTINEL-1 Synthetic Aperture Radar (SAR). The Interferometric Wide Swath Mode imagery Ground Range Detected Imagery for the 2nd of January 2019 was acquired for the study area, processed using Sentinel Application Platform (SNAP) and the oil spill detection algorithm was applied on the Amplitude Vertical-Vertical Band. After preprocessing, the non-polluted areas were found to have high backscatter (amplitude >18.0). For the impacted areas, lower values were recorded - amplitude decibel value of between 15.9 and 18.0. A total of 329 polygons of oil slick were identified, covering an area of 46.34 km^2. The impacted surface area ranges between 0.000064 – 15 km^2. The farthest impacted surface can be found around 18.25km from the Bonny coastline. Results showed that a significant proportion of the oil slicks are concentrated along the upper reaches of the Bonny River spanning Okrika and Ogu/Bolo LGA. Towards the nearshore, the oil slicks were disaggregated into several units. Contiguous units were found closer to the banks and coastline. Out of the 329 polygons, 14 were identified along the New Calabar River, emptying into the Bonny Estuary. The impacted surfaces along the New Calabar River were smaller in size compared to those found along the Bonny River. The results identified the pattern and distribution of oil slicks across a segment of the Gulf of Guinea dominated by oil and gas industry activities. This study highlighted the potential of remotely sensed data to support coastal pollution management efforts. It further highlighted the potential for spatiotemporal monitoring of oil slicks along coastal and inland waters. Challenges for deploying such a platform include the high computing power required and the lack of in-situ monitoring data for validation.*

KEYWORDS: Oil pollution, Modelling, Synthetic Aperture Radar, Coastal Waters, Inland Waters

INTRODUCTION

The environment of the Niger Delta has suffered contamination for more than 50 years from oil and gas production activities, rapid industrialization and urbanization, agricultural, and domestic effluent discharges. Contaminated runoff from the hinterland always finds its way to the coast via the extensive network of rivers and creeks across the delta. Some of the commonly reported contaminants include; metals (Pb, Cd, Cr, Ni, Fe, Zn, Cu, V and Mg) whose concentrations are reportedly high in sediments and seafood samples (Davies, Allison, & Uyi, 2006). Others include Organotin compounds (OTCs), polycyclic aromatic hydrocarbons (PAHs), total hydrocarbons (THCs) and radionuclides.

Across any landscape hazards are usually present, however, when adequate and appropriate actions are not taken such hazards can result in disaster. Therefore, it is apparent that hazards are inevitable, it is the human response and impacts that often dictate whether such hazards become disasters. Oil spills across any environment are very hazardous because of their social, environmental, and economic impacts. Currently, across the Niger Delta Coast, there are substantial social, economic, and environmental costs. An oil spill could be because of an accidental release of oil from platforms, tankers, wells, rigs, vandalism/oil theft etc. into the environment. Over the years there have been numerous examples of major oil spills in Nigeria, the work of Nwilo and Badejo (2006) and a look at the Oil Spill Monitor (https://oilspillmonitor.ng/) gives a clear indication that the occurrence of such disasters is still prominent across the oil-producing regions of the country (Plate 1).

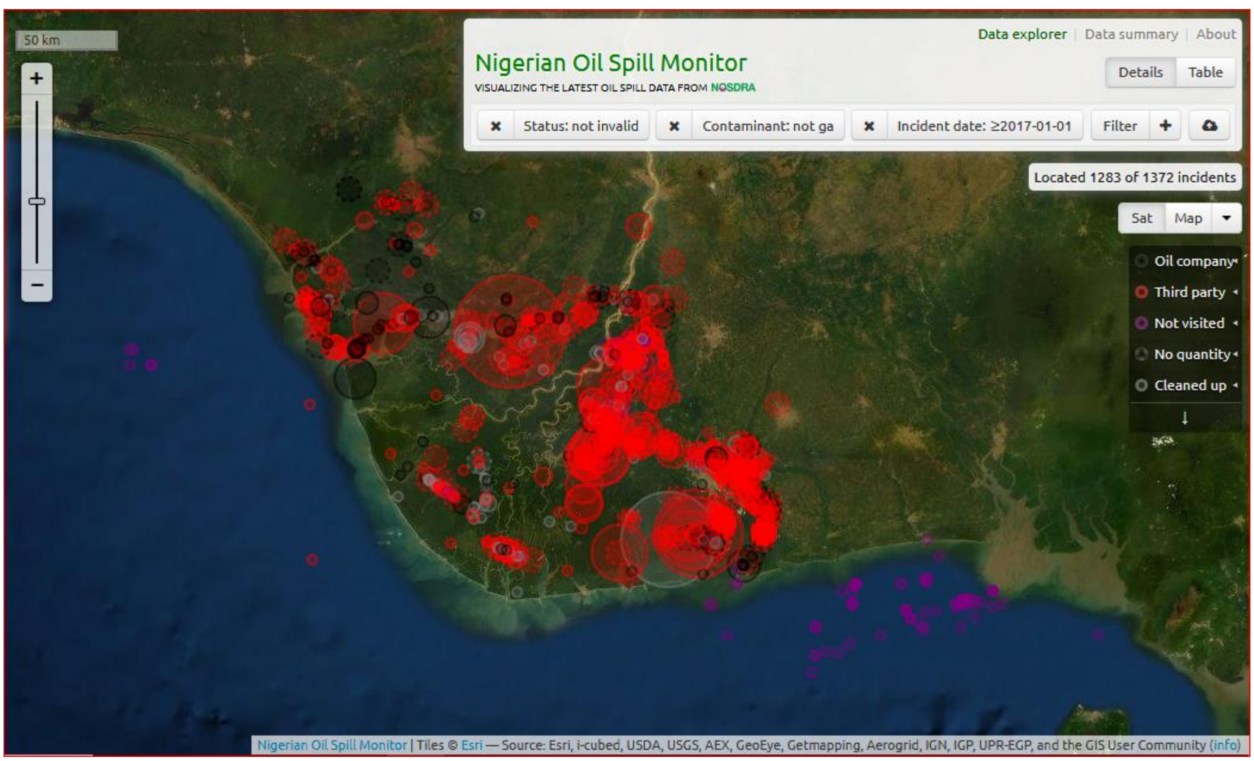

Plate 1: Snapshot of Incidents of oil spills from 2017 till date

It is very clear that even with the best laid-out plan, the management of disasters requires an iterative and continuous evolution of techniques, actions and measures (Lawal & Oyegun, 2017). There is a clear understanding that oil spill' impacts are often worse due to a lack of adequate data and information to guide actions and deployment of resources for preparedness and response. The same can be said in the management of the aftermath of many of the oil spills currently evident across many parts of the shipping lane. The presence of oil on the coastline and shipping routes is currently hurting the shipping and haulage industry. Especially, for those who decided to berth at ports across the Niger Delta. Currently, the presence of oil across the coastal waters is a disincentive for many major shipping companies from berthing in ports across the Niger Delta. In compliance with the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) ships are required to clean their hull before approaching the next destination. As such shippers incurred additional costs to ensure this cleanup is carried out.

The pervasiveness of oil slick and sheen across the coastal waters among other challenges is currently hindering the development of the region's ports as the dominant point of call for ships in West Africa. In addition to this, there is the extensive environmental impact and the inadequate cleanup operations. To fulfil the huge potential of the region's ports (Figure 1) due to their strategic position, effective measures must be in place to clean up the shipping lane. Improvement in economic condition (i.e. creation of jobs) could also have a knock-on effect on the security challenges in the region. With this understanding there is a need to map and model the dynamics of oil pollution across the coastal waters of the Niger Delta, thereby providing evidence-based and data support management solutions. The management of oil pollution has the potential of supporting regional development economic plans which could change the narrative of the region for the better.

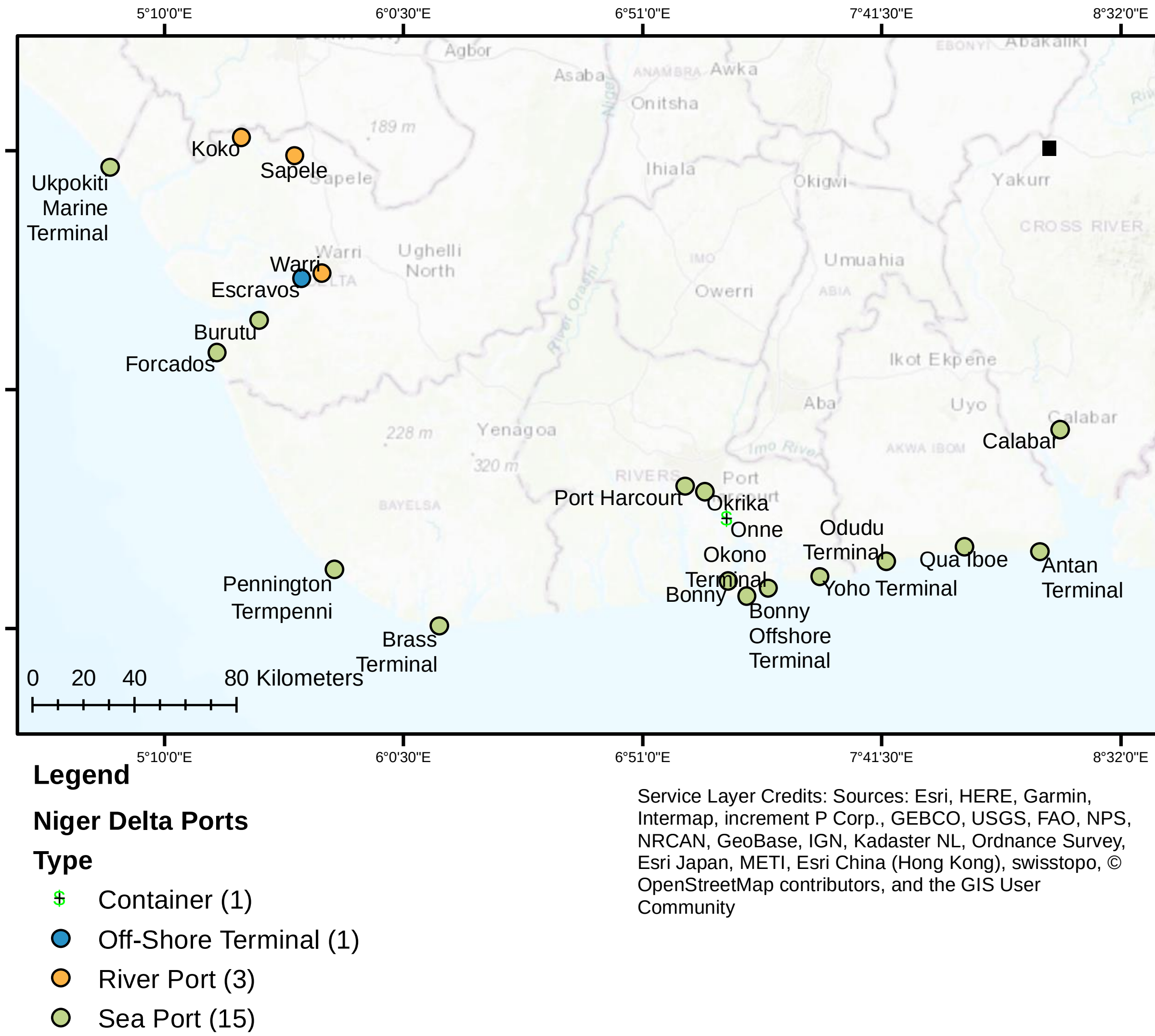

Figure 1: Ports Across the Niger Delta Region

The effects of contaminants have been reported to include threats to food security, the environment and livelihood (Lawal & Oyegun, 2017). Artisanal fisheries in the Niger Delta and Nigeria's coastal waters support the livelihood of its inhabitants, thus management of pollution also supports ensuring the management of contaminants entering the diets of the populace. Fish remains an important part of the diet of Nigerians, especially for coastal and riverine communities such as the inhabitants of the Niger Delta area. In addition, the current pervasiveness of oil pollution across the coastal waters is a negative incentive for the economic competitiveness of the Ports in the region, thereby limiting the economic development of the region.

Management of pollution, development and implementation of contingency plans requires adequate and timely data (Lawal & Oyegun, 2017). Therefore, there is a need to set up monitoring and state of the art facility to provide data for decision-makers across the region in the management of oil pollution along the coastal waters of the region. To support the creation of a decision support system (DSS) for coastal waters oil pollution management, there is a need to document the extent and concentration of oil pollution in the marine environment, especially along the shipping lanes and ports in the region. The lack of this information impedes the formulation of policies and measures to address this problem. Thus, there is a need to fill this data gap to support holistic environmental management of the marine environment and the coastal waters. This would help in providing science-based policy and data-driven solutions to ensure effective and efficient clean-up of the shipping lanes across the region. With this understanding, this study is aimed at showcasing the modelling and mapping of oil pollution along a selected region of the Gulf of Guinea. To achieve this, the study modelled oil slick on water using SENTINEL-1 Synthetic Aperture Radar (SAR), mapped the location of such slick, and quantified the area impacted. This is geared towards developing reliable evidence to support appropriate policy for environmental monitoring and management of oil pollution across the shipping lanes and seaports in the region (providing an evidence base and decision support system). It is expected that improvement in management of oil pollution will enhance the regional economic development plans thereby changing the narrative of the region for the better.
Both legal and illegal operations in the oil and gas industries lead to pollution of the waterways and harbours. However, when the management of the spill episodes is inadequate, the contamination often spills over into extensive areas of land and ocean. This creates a negative spiral which impacts the environment and the social and economic spheres. Therefore, to stop this negative spiral and create a new economic environment, there is a need for intervention that is data and evidence-driven to support the development of an oil pollution-free environment.

Garcia-Pineda et al. (2020) explored the potential of SAR in discriminating oil emulsions within detected oil slicks. They presented an innovative approach for the rapid classification of oil types and estimated thicknesses, aiming to deliver actionable information about thick oil and oil emulsions within an operational timeframe. Multiple satellite datasets were acquired, including fully polarimetric C-band SAR imagery from RADARSAT-2, multispectral imagery from ASTER and WorldView-2, and airborne polarimetric UAVSAR L-band sensor data.

Garcia-Pineda et al. (2020) showcased a satellite SAR-based product of oil delineation by relative thickness to a responding vessel in near-real-time. The proof-of-concept test, conducted during field operations in the Gulf of Mexico, showcased a remarkable 42-minute latency between RADARSAT-2 data acquisition and the delivery of actionable information to the responding vessel via NOAA. The successful classification of oil types and thicknesses, coupled with near-real-time delivery capabilities, suggests promising prospects for the integration of satellite-based assets in future oil spill response efforts.

Löw, Stieglitz, and Diemar (2021) carried out an application of Sentinel-1 and -2 instruments and the incorporation of multi-temporal information and spatial predictor variables to achieve high classification accuracy in mapping oil spills. In addition, they utilised machine learning algorithms for classifying terrestrial oil spills. The study demonstrates that these algorithms can achieve a remarkable classification accuracy of over 90% using Sentinel-1 and -2 data. Moreover, Löw et al. (2021) findings indicated a significant enhancement in classification accuracy (>95%) through the incorporation of multi-temporal information and spatial predictor variables. The inclusion of temporal data and factors quantifying proximity to oil production infrastructure, such as pipelines and oil pads, highlights the importance of contextual information in refining the precision of oil spill mapping efforts. Results from this study suggest that mapping terrestrial oil spills with freely available Sentinel satellite images offers an accurate and efficient means for the regular monitoring of oil-impacted areas. The combination of open-access satellite data and machine learning algorithms provides a cost-effective and scalable solution for continuous surveillance, enabling timely responses to environmental challenges.

Rajendran et al. (2021) conducted a study focusing on the Wakashio oil spill off Mauritius in the Indian Ocean on August 6, 2020. The study leveraged Sentinel-1 Synthetic-Aperture Radar (SAR) C-band data acquired between July 5 and September 3, 2020, to identify and delineate the occurrence and distribution of the Wakashio oil spill. The interpretation of VV polarization images revealed dark, warped patches indicative of the oil spill's presence. Additionally, the study employed Sentinel-2 data and various band ratios, such as (5 + 6)/7, (3 + 4)/2, (11 + 12)/8, and spectral bands 3/2, (3 + 4)/2, (6 + 7)/5, to detect and characterize the oil spill, showcasing the versatility of Sentinel sensors in capturing the spill's nuances.

Furthermore, Rajendran et al. (2021) used spectral bands 4, 3, and 2 from Sentinel-2 data to distinguish between very thick, thick, and thin oil spills. The study effectively illustrated the distribution of spilt oil over the lagoon and offshore, highlighting the accumulation on coral reefs and along the coast. By analysing images acquired after August 21, 2020, the researchers mapped the post-oil spill distribution along the coast, providing valuable insights into the persisting impact of the spill. The accuracy of Rajendran et al. (2021) oil spill mapping was rigorously assessed through the classification of SAR-C data and decorrelated images of the Multispectral Instrument (MSI) data. With the utilisation of the Parallelepiped supervised algorithm and confusion matrix, Rajendran et al. (2021) reported an overall accuracy averaging 91.72% and 98.77%, with Kappa coefficients of 0.84 and 0.96, respectively. The study's findings were further validated through field studies, demonstrating the reliability and effectiveness of the satellite-derived results.

DATA AND METHOD

Study Area

The areas under consideration for this study—Bonny River, Cawthorne Channel, and New Calabar River—hold significant importance in the Gulf of Guinea, especially within the context of this study. Bonny River, located in the Niger Delta region of Nigeria, serves as a vital waterway connecting the Bight of Bonny to inland areas (Jones, 2000). Notably, the Bonny Terminal, a major oil and gas export terminal, raises concerns about potential oil spills and pollution. The surrounding mangrove swamps and diverse ecosystems highlight the ecological sensitivity of this region, where oil pollution could have severe consequences for aquatic life and the livelihoods of local communities (Ezeali, Nwachukwu, & Okonkwo, 2023).

Situated in the eastern part of the Niger Delta, Cawthorne Channel acts as a crucial conduit between the Bonny River and the Gulf of Guinea. This channel's significance lies in its potential role as a pathway for the spread of oil pollution between inland and coastal areas (Abam & Nwankwoala, 2020). Given its importance for shipping and transportation, accidents or spills in the Cawthorne Channel could have far-reaching consequences for the marine environment.

New Calabar River, located in Rivers State, Nigeria, is another essential waterway in the Niger Delta (Abam & Nwankwoala, 2020). Like Bonny River, it plays a vital role in the transportation of oil and gas products, posing a heightened risk of oil pollution incidents. The river's flow through mangrove areas and its rich biodiversity make it particularly vulnerable to ecological damage in the event of oil pollution (Uzamere, Kpee, & Momta, 2023).

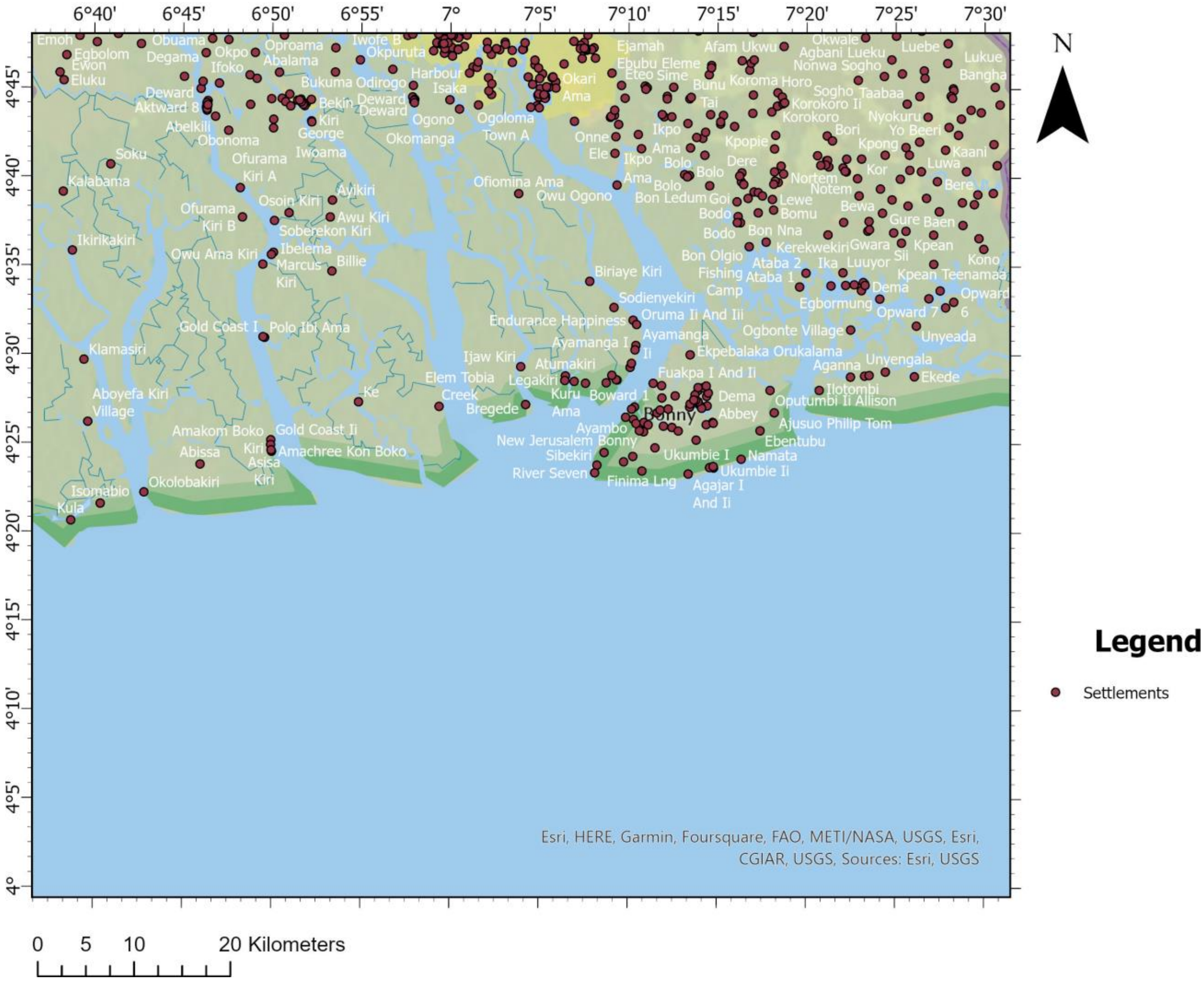

Figure 2: The study area, its settlements, and environs

The Gulf of Guinea, off the coast of West Africa, is known for its oil reserves. Akwa Ibom, Abia, Cross River and Ebonyi are significant players in the oil sector with Nigeria (Chidiobi & Ibekwe, 2022). The region's legal oil sector is under governmental regulations and oversight by bodies such as the Department of Petroleum Resources (DPR). These regulations guarantee compliance with safety regulations and environmental standards. Legal oil operations are significant contributors to Nigeria's economy through taxes, royalties, and other fiscal arrangements with oil companies (Olawuyi & Tubodenyefa, 2018).

However, regardless of the legal framework, there is a proliferation of illegal oil operations within the Gulf of Guinea such as oil theft, oil bunkering and artisanal refining (Balogun, 2018). These illegal oil operations take place along the coastal areas (including the creeks and swamps) within the region. The Gulf of Guinea has suffered considerable damage from the destruction of ecosystems, and livelihoods in the wake of these illegal operations (Balogun, 2018).

The Niger Delta and the Northern Gulf of Guinea – Bioko basins are the major drainage basin within the study area. The Niger Delta is one of the largest and most important deltaic regions in Africa. It encompasses parts of Nigeria, Cameroon, Equatorial Guinea, and other neighbouring countries (Lehner & Grill, 2013). They are of great ecological significance, supporting a wide range of ecosystems, including mangroves, estuaries, and wetlands. These areas are home to various marine and freshwater species, and they provide essential habitats for migratory birds and other wildlife.

Data

Data Acquisition

For this study, SENTINEL-1 Synthetic Aperture Radar (SAR) data were sourced from the Copernicus Open Access Hub. This is a freely available dataset with a good coverage of our study area. Sentinel-1A was launched on the 3rd of April 2014. The study utilised the data acquired on the 2nd of January over the study area.

The type of SAR data used was the Ground Range Detected Imagery (GRD). According to the European Space Agency (2022), it is made up of focused SAR data detected from multi-looked images. The dataset is projected to ground range using the Earth ellipsoid model and corrected with the terrain height specified in each product. Level 1 data which is georeferenced and provides a slant-range geometry. Pixel values as the name of the product is the detected magnitude while the phase information is lost. The product has approximately square spatial resolution and square pixel spacing, and the multi-look processing ensures the reduction of speckles in the SAR data. The interferometric Wide (IW) swath mode was used. It has a spatial resolution of 20.4m by 22.5m.

Data Processing

This study utilised the Sentinel Application Platform (SNAP) for preprocessing and analysis of SAR images. The SAR instrument delivers several black-and-white images and objects with varying properties and reflectivity appearing with different textures and intensities on them. The sea surfaces have a homogenously bright appearance due to their natural roughness and high reflectivity (Martin, 2014). Also, oil slicks from various sources (e.g. ship discharges, leakage from oil pipes, discharges from ships and natural phenomena such as rain cells, alga-blooms or local winds) can influence its texture (Jafarzadeh, Mahdianpari, Homayouni, Mohammadimanesh, & Dabboor, 2021).

Furthermore, oil on the water surface generates very thin films that dampen the capillary ocean waves. In the subsequent scanning of such areas with microwave radiation with appropriate wavelength, the reflected wave interferences with the incident radiation according to the Bragg scattering principle (Jackson & Lyzenga, 1990). This explains why the oil films have an appearance of dark objects against the bright ocean surface when scanned with SAR instrument.

This study also carried out adaptive thresholding which is used for image segmentation by setting all pixels above a certain value to the foreground value and the rest to the background value. The thresholding employs a global average backscatter value for the entire image, while the adaptive threshold algorithm utilises a local average backscatter value which is estimated for pixels in a large window. This process is dynamic because the window is moved across the image and a new average backscatter level must be estimated for each segment of the image.

A threshold is set to *n* decibels below the local average calculated before. The value of every pixel within the window is estimated and set as a dark spot if its value is below the threshold *n*. If it is above the threshold value *n*, it is set as a background pixel. All detected pixels are then clustered into a single cluster and those having a size smaller followed by an elimination of all pixels with a smaller size than the predefined size set by this study. The outputs were further taken to the ArcGIS Pro environment for further processing.

RESULTS AND DISCUSSION

Polluted Area Detection

A profile plot (Figure 2) was produced for a segment (Figure 3) that is representative of the study area. From the profile plot, this indicated that surfaces with oil slick have a backscatter amplitude value ranging from 15.9 to 18.0. The profile plot (Figure 2) further revealed that non-polluted areas exhibited higher backscatter amplitudes above 18.0. With this understanding, it is possible to discern and classify impacted and non-impacted areas across the study area. The visualisation of the backscatter in Figure 3, shows that based on ranges identified from Figure 2, the darker areas are impacted while grey areas could be designated as non-impacted. It should be noted that this classification is based on the day of observation. Thus, the oil slick observation could vary over time. Therefore, the designation as impacted and non-impacted is based on the date of observation.

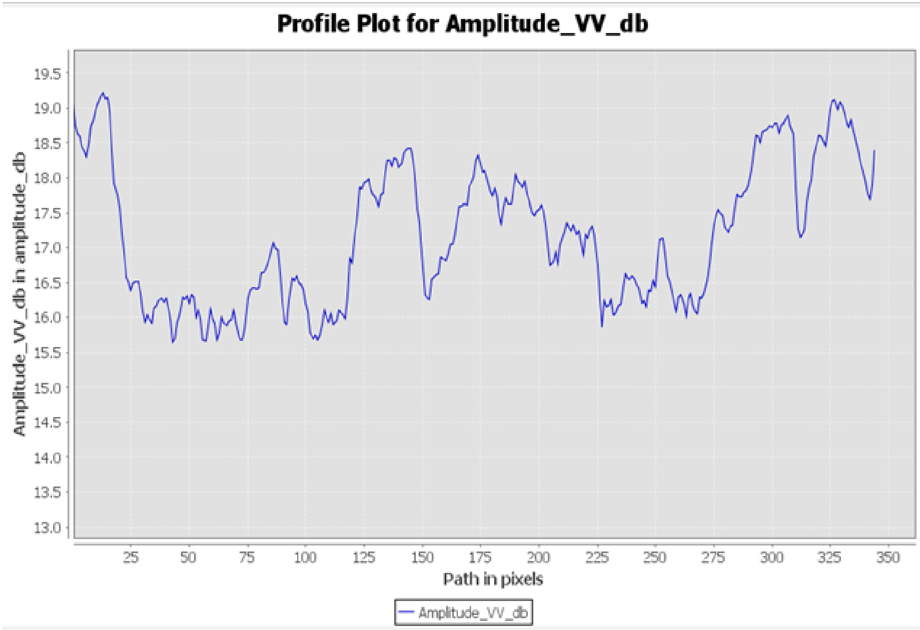

Figure 2 Profile Plot for Amplitude Across the Study Area

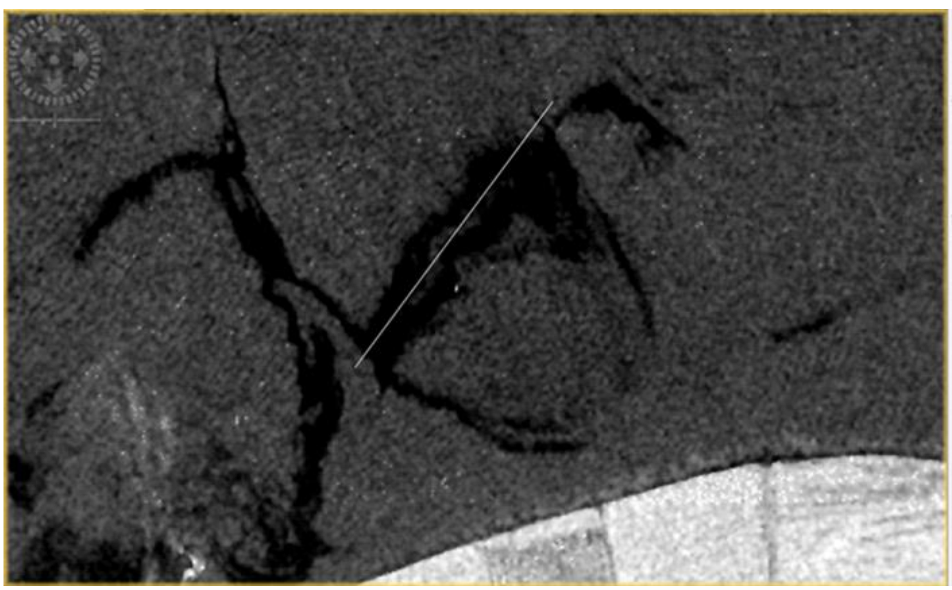

Figure 3 Areas Impacted by Oil Spill Across the Study Area

Oil Spill Impact Distribution Across the Study Area

A total of 329 distinct polygons, representing identified oil slicks, collectively span an area of 46.3 km². The variability in the sizes of these slicks, ranging from 0.000064 km² to 15 km², underscores the heterogeneous nature of the impacted area across the study area. Table 1 provides characteristics of the distribution of the oil slick polygons in the study area. The mean area of the identified oil slick polygons was 0.140979 Km², indicating the typical size of oil slicks within the study area. The minimum observed area, at 0.000064 km², indicated that across the vast areas surveyed the smallest unit area of the oil slick on the surface of the water can still be significant ($64m^2$). The maximum observed area stood at 15.025342 km², indicating that there can be a large swath of oil slick across the surface within the study area. This underscores the potential for larger-scale environmental impact. The standard deviation, calculated at 0.907372 km², reflects the dispersion of oil slick areas around the mean, emphasising the heterogeneity in the size of the impacted or polluted surfaces.

Table 1. Oil Spill Impact Distribution Across the Study Area

Statistics	**Values (Km^2)**
Mean	0.140979
Minimum	0.000064
Maximum	15.025342
SD	0.907372

Oil Slick Distribution

The distribution of the oil slick, particularly in identified impacted areas such as Bonny River, New Calabar River, and the Bonny Estuary was presented in Figure 4. The presence of oil slicks in this strategically significant area river underscores the potential environmental risks associated with oil-related activities in the region. Figure 4 shows that oil slicks can be found further inland in considerable sizes, especially along the Bonny River. Noteworthy, is the lesser presence of oil slick along the new Calabar river but only around the mouth of the river. This indicated that the potential source of the oil slick is from neighbouring Rivers or nearshore pollution sources.

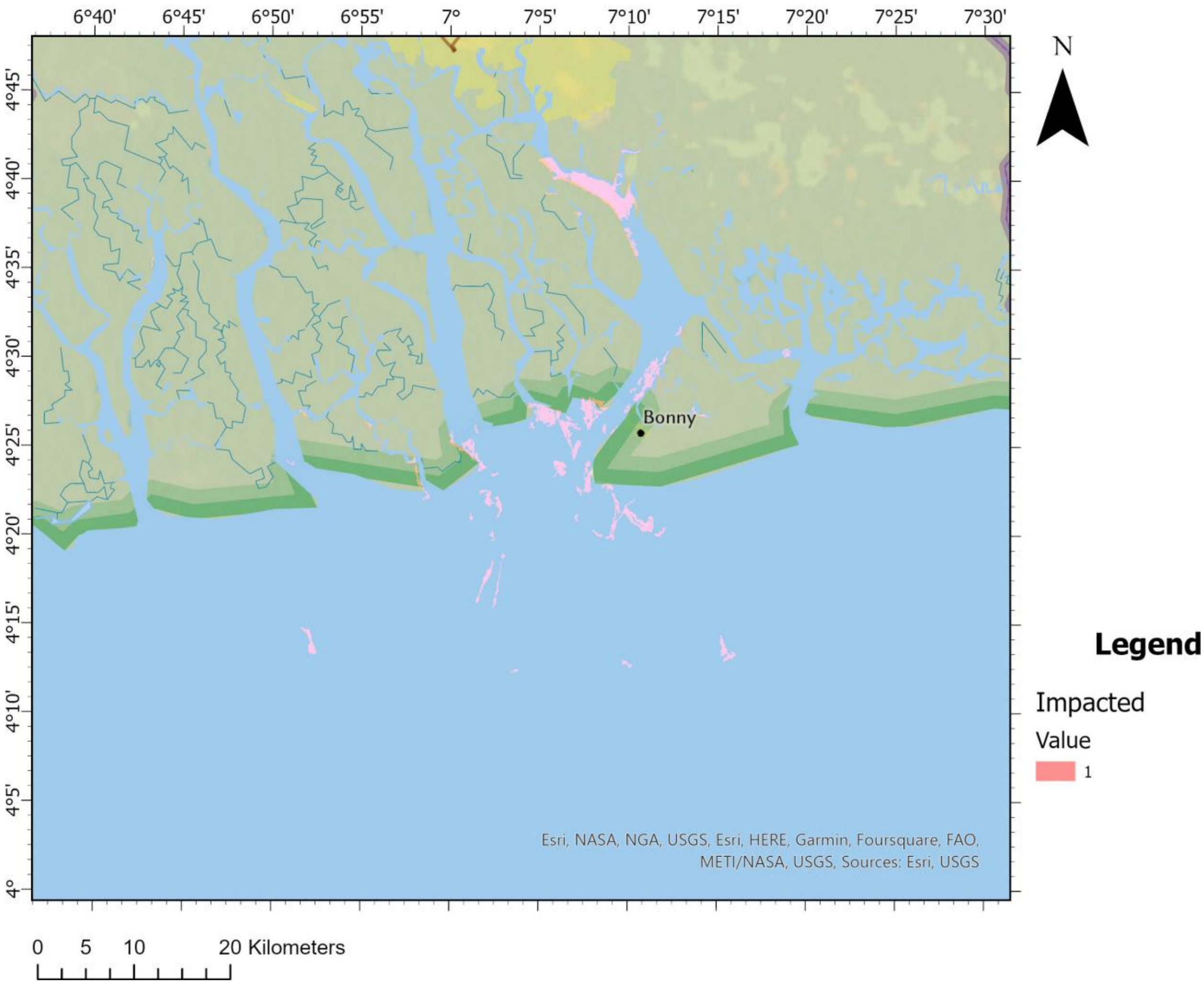

Figure 4. Oil Slick Distribution Along the New Calabar River and the Bonny Estuary.

Figure 5 shows impacted areas, specifically the upper reaches of Bonny River and Okrika Ogu/Bolo Local Government Area (LGA). Around the upper reaches of Bonny River, there is a significant presence of oil slick. This area holds particular importance due to its proximity to potential sources of oil pollution and its role as part of the broader river network. With the size of the oil-impacted surface along the river, there is an indication that due to the characteristics of the waterbody, natural attenuation of the oil is limited thus the large, impacted surface is observed. The observation is also indicating the potential presence of polluting activities nearby.

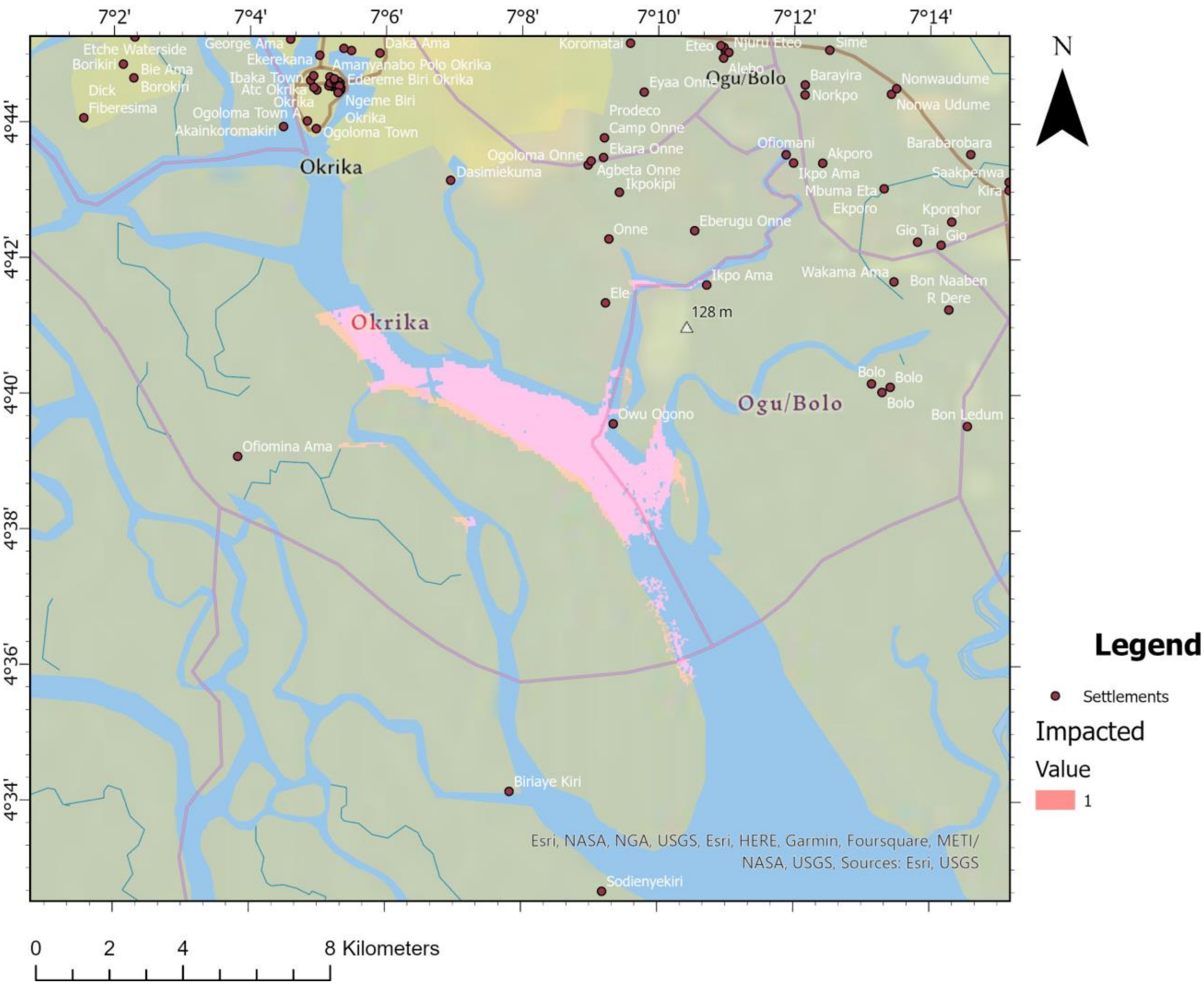

Figure 5. Oil Slick Distribution Along Bonny River and Okrika Ogu/Bolo LGA

Figure 6 shows oil slick distribution along the channel and the Atlantic which provides an overview of the spatial extent and dispersion of oil pollution in the broader marine environment. There is evidence of oil slicks along the coast. This could be attributed to both nearby sources of pollution as well upstream sources. Moreso, there are significant expansion of these oil slicks further into the Atlantic Ocean (Figure 6). This expansion into the Atlantic is significant, as it highlighted the potential for upstream or nearshore oil slicks to extend into the beyond nearshore areas. This could be attributed to the influence of the biophysical (e.g. ocean currents and waves) and human factors (water vessels movement). This thus, showcased the potential for long-range transport of pollutants and the range of areas for which the environmental impact could be recorded in marine ecosystems.

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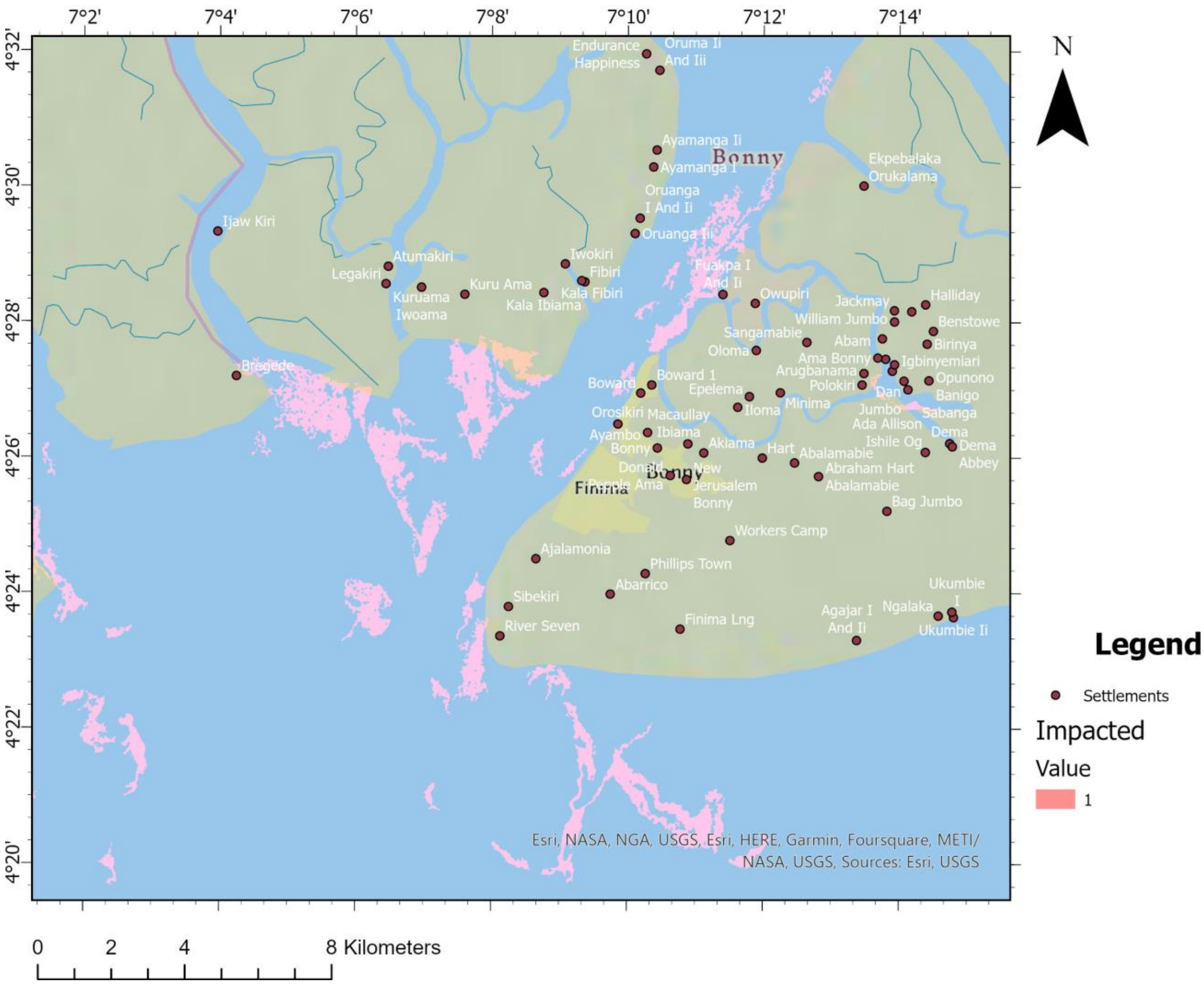

Figure 6. Oil Slick Distribution Along the Atlantic

DISCUSSION

One noteworthy observation is the distribution of oil slicks within the upper reaches of the Bonny River. The compact nature of many oil slicks in this region suggests a potential concentration of pollution sources or distinct patterns of oil dispersion. This is important due to the limited natural attention possibilities within this environment. For instance, a concentrated source may necessitate more focused pollution control or attenuation measures, while fragmented slicks closer to the coastline might require enhancement of natural attenuation depending on the size of the impacted surfaces. UNEP (2016) showed that high wave exposure is a major factor in the spreading of spilt oil across coastal areas. This is thus, subject to the viscosity of the oil, the water temperature, wind speed, current, tidal stream, etc. Essentially, as natural wave action can aid the attention of the spilt oil, it also contributes to the spreading of the spilt oil (Lawal & Oyegun, 2017).

The comparison between impacted areas along the New Calabar River and the Bonny River unveils an intriguing distinction between the two. The oil slicks observed along the New Calabar River are not only smaller in size but also fewer in quantity compared to those along the Bonny River. This discrepancy may be an indication of a lower level of activities around the period of our observation. Temporal analysis can be used to verify such indications. However, irrespective of the level of activities, the presence of oiling around the two rivers has a considerable negative environmental impact. This is because these areas have been reported to have low fetch length(thus there is minimal potential for natural cleaning) and are highly sensitive to oiling (Lawal & Oyegun, 2017).

The identification of oil slicks as far as 18 kilometres from the coastline underscores the potentially far-reaching impact of oil pollution in the Gulf of Guinea. These findings highlighted the need for a comprehensive approach to environmental monitoring and response strategies that extend beyond immediate coastal zones. Understanding the spatial extent of oil slicks in offshore areas is crucial for assessing the broader ecological implications and designing policies that address not only nearshore environments but also the interconnected marine ecosystems further from the coast.

CONCLUSION

This study has provided insight into the patterns and distribution of oil slicks in a Gulf of Guinea region heavily influenced by the activities of the oil and gas industry (both legal and illegal). The analysis carried out has highlighted the significance of remotely sensed data in supporting effective coastal pollution management efforts. The findings underscore the importance of continuous spatiotemporal monitoring of oil slicks in both coastal and inland waters, providing crucial insights into the dynamic nature of oil pollution.

The potential of remotely sensed data to show the distribution of oil slicks across several areas is noteworthy. This technology not only enhances our understanding of pollution patterns but also provides valuable data for informed decision-making in environmental management. There is an urgent need for a proactive monitoring platform to address the challenges posed by oil pollution in the Gulf of Guinea. However, it is acknowledged that implementing such a platform comes with inherent challenges, notably the requirement for substantial investment in high-performance computing infrastructure. Additionally, the collection of validation data is a critical component, adding to the complexity and resource demands of establishing an effective monitoring system.
This study advocates for the integration of remotely sensed data into coastal pollution management strategies in the region. The identified challenges in implementing a monitoring

platform underscore the need for collaborative efforts to overcome obstacles and establish effective systems for the continuous monitoring of oil pollution in the Gulf of Guinea.

REFERENCES

Abam, T., & Nwankwoala, H. (2020). Hydrogeology of eastern Niger delta: a review. *Journal of Water Resource and Protection, 12*(9), 741-777.

Balogun, W. A. (2018). *Crude oil theft, petrol-piracy and illegal trade in fuel: an enterprise-value chain perspective of energy-maritime crime in the Gulf of Guinea*: Lancaster University (United Kingdom).

Chidiobi, O. C., & Ibekwe, J. C. (2022). Oil Exploitation, Environmental Issues and Resource Curse in a Post-Colonial Niger Delta Region of Nigeria: The Unending Search for Peace, 1960-2009. *Advances in Social Sciences Research Journal, 9*(11).

Davies, O. A., Allison, M. E., & Uyi, H. S. (2006). Bioaccumulation of heavy metals in water, sediment and periwinkle (Tympanotonus fuscatus var radula) from the Elechi Creek, Niger Delta. *African Journal of Biotechnology, 5*(10).

European Space Agency. (2022). Ground Range Detected - Sentinel-1 SAR Technical Guide - Sentinel Online - Sentinel Online. Retrieved from https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-1-sar/products-algorithms/level-1-algorithms/ground-range-detected

Ezeali, V. O., Nwachukwu, C. C., & Okonkwo, K. O. (2023). Marine Transportation on Oil and Gas Projects in Bonny Island, Rivers State. Nigeria. *International Journal of Education, Business and Economics Research (IJEBER), 3*(5), 182-192.

Garcia-Pineda, O., Staples, G., Jones, C. E., Hu, C., Holt, B., Kourafalou, V., . . . Haces-Garcia, F. (2020). Classification of oil spill by thicknesses using multiple remote sensors. *Remote Sensing of Environment, 236*, 111421. doi:https://doi.org/10.1016/j.rse.2019.111421

Jackson, F., & Lyzenga, D. (1990). Microwave techniques for measuring directional wave spectra. In *Surface Waves and Fluxes: Volume II—Remote Sensing* (pp. 221-264): Springer.

Jafarzadeh, H., Mahdianpari, M., Homayouni, S., Mohammadimanesh, F., & Dabboor, M. (2021). Oil spill detection from Synthetic Aperture Radar Earth observations: a meta-analysis and comprehensive review. *GIScience & Remote Sensing, 58*(7), 1022-1051. doi:10.1080/15481603.2021.1952542

Jones, G. I. (2000). *The Trading States of the Oil Rivers: A Study of Political Development in Eastern Nigeria*: Lit.

Lawal, O., & Oyegun, C. U. (2017). Geographic information systems-based expert system modelling for shoreline sensitivity to oil spill disaster in Rivers State, Nigeria. *Jàmbá: Journal of Disaster Risk Studies, 9*(1), 1-8.

Löw, F., Stieglitz, K., & Diemar, O. (2021). Terrestrial oil spill mapping using satellite earth observation and machine learning: A case study in South Sudan. *Journal of*

Environmental Management, 298, 113424. doi:https://doi.org/10.1016/j.jenvman.2021.113424

Martin, S. (2014). *An Introduction to Ocean Remote Sensing*: Cambridge University Press.

Nwilo, P. C., & Badejo, O. T. (2006). Impacts and management of oil spill pollution along the Nigerian coastal areas. *Administering Marine Spaces: International Issues, 119*, 1-15.

Olawuyi, D. S., & Tubodenyefa, Z. (2018). Review of the environmental Guidelines and standards for the petroleum industry in Nigeria (EGASPIN). *OGEES Institute*.

Rajendran, S., Vethamony, P., Sadooni, F. N., Al-Kuwari, H. A.-S., Al-Khayat, J. A., Seegobin, V. O., . . . Nasir, S. (2021). Detection of Wakashio oil spill off Mauritius using Sentinel-1 and 2 data: Capability of sensors, image transformation methods and mapping. *Environmental Pollution, 274*, 116618. doi:https://doi.org/10.1016/j.envpol.2021.116618

UNEP. (2016). Global Marine Oil Pollution Information Gateway: What happens to oil in sea water? Retrieved from http://oils.gpa.unep.org/facts/fate.htm

Uzamere, O., Kpee, F., & Momta, P. N. (2023). Determination of levels of physicochemical parameters in water samples of New Calabar River, Rivers State, Nigeria. *Faculty of Natural and Applied Sciences Journal of Scientific Innovations, 4*(1), 55-63. Retrieved from https://www.fnasjournals.com/index.php/FNAS-JSI/article/view/117