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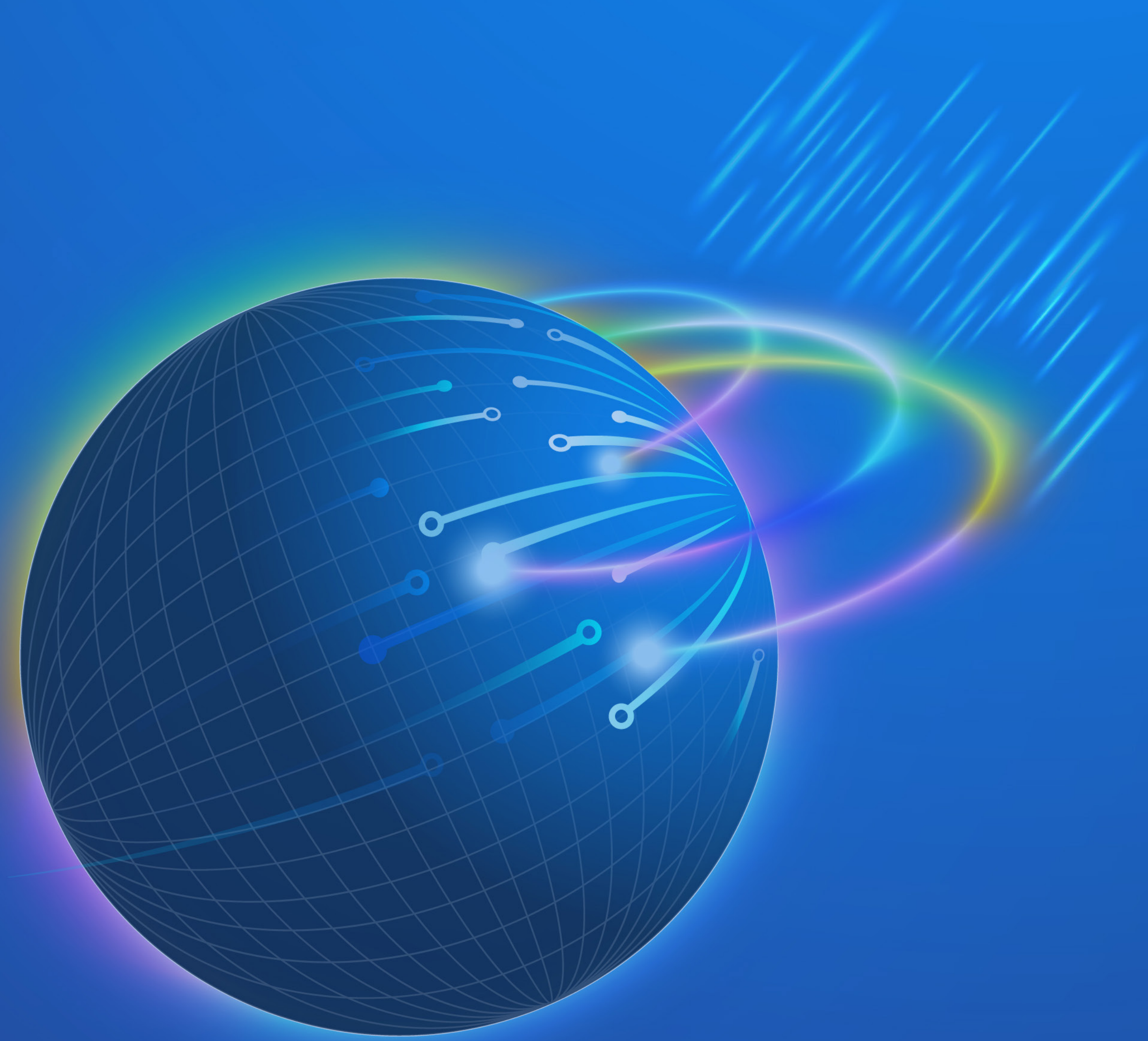

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Geospatial Assessment of Oil Spill's Impact in Obio/Akpor Local Government Area Rivers State, Nigeria

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ABSTRACT

Environmental degradation resulting from oil spills has emerged as a critical issue requiring immediate attention. This study uses geospatial techniques to investigate the impact of oil spills in Obio/Akpor Local Government Area of Rivers State. Landsat images, administrative map of the study area and historical oil spill data were data used in carrying out this study. The images were pre-processed through atmospheric and geometric corrections. Spatial analysis of four remote sensing indices-Normalized Difference Vegetation Index (NDVI) for assessing vegetation health, Normalized Difference Water Index (NDWI) for detecting water bodies, Land Surface Temperature (LST) for measuring surface temperature, and Normalized Difference Built-Up Index (NDBI) for identifying built-up areas-was conducted using the raster calculator in ArcGIS. The study employed the Analytical Hierarchy Process (AHP) to assign weights to these indices based their relative significance regarding oil spill impact. Subsequently, reclassification and integration of this information were done to generate Oil Spill Index (OSI) maps for 2003, 2013, and 2023. Validation of the Oil Spill Index (OSI) of various points before and after an oil spill incident was performed, specifically contrasting 2003 with 2013 and 2023 OSI values. This was to affirm the accuracy and predictive capability of the OSI maps in identifying oil spill-prone areas. Findings revealed OSI values for 2003 and 2013, indicating a range of 1.04 to 3.48 for 2003, with a noticeable increase observed in 2013, expanding the range to 3.08 to 4.72. Similarly, a comparison of OSI values between 2003 and 2023 indicates OSI values, ranging from 1.64 to 3.92 in 2003, then in 2023 after the oil spill incidents, there were notable changes in the OSI values, with the range shifting to 3.2 to 4.84. This suggests a significant increase in the impact of oil spill on the affected areas over the two-decade. This comprehensive index map serves as a tool for monitoring and assessing the effects of oil spills on the study area, thereby achieving the research objectives effectively.

INTRODUCTION

Crude oil is a naturally occurring liquid found beneath the earth's surface, which can be converted into fuel (Grema *et al.*, 2023). It is a mixture of hydrocarbons (Sephton and Hazen, 2013). However, the extraction process due to poor management has led to oil spills. An oil spill occurs when liquid petroleum is accidentally or purposefully released into the environment. According to Ejiba *et al.*, (2016), oil spills are caused by deteriorating infrastructure, malfunctioning machinery, operational accidents, sabotage, and theft. The dangers associated with oil spills are numerous and could make life unbearable for the inhabitants of impacted regions. Environmental problems brought on by oil spill contamination grew in severity throughout the 20th century.

Among the nine Niger Delta states, Rivers State accounted for more than half of all oil spill occurrences reported by Shell Petroleum Development Company (SPDC) (Mohamadi *et al.*, 2016). Obio/Akpor Local Government Area (Study Area) has experienced several oil spill incidents. For example, on November 6th, 2020, a Punch newspaper publication by Dennis Naku, reported the oil spill incident that occurred at Umuchem community in Obio/Akpor LGA. Concerned that there would be an explosion, the residents of the Umuchem community signaled the alarm. Another incident occurred on December 19 when a pipeline operated by the Shell Petroleum Development Company, SPDC, burst and spilled crude oil in the Eneka community in Obio/Akpor Local Government Area (Udoma, 2019). On December 3rd, 2003, an oil spill occurred from an 8" pipeline between Agbada FS and Nkpoku manifold operated by SPDC, at Rukpokwu community in Obio/Akpor LGA of Rivers State (Bassy, 2004). It was estimated that 81 barrels of crude oil leaked into the environment.

Oil spills have the potential to destroy the ecosystem if left unchecked or properly managed (Agunobi *et al.*, 2014). In addition, the residents of Obio/Akpor Local Government Area have cried out for assistance regarding the frequent oil spills, to Shell Petroleum Development Company (SPDC), humanitarian organizations, and state and local governments (Naku, 2020). Therefore, it is necessary to properly analyze data and offer information on this matter. Hence, this study investigated the extent, severity, and impact of these spills using environmental parameters such as vegetation, waterbodies, land surface temperature, and built-up areas through geospatial analysis. The following research questions enable the

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research aim to be achieved:

(i) What are the temporal patterns in NDVI, NDWI, LST, and NDBI?

(ii) What is the relative significance of each criterion in accurately expressing the extent and severity of oil spills in the study area?

(iii) What is the oil spill index of the study area?

(iv) How accurate is the oil spill index?

This study addresses these issues using geospatial method, utilizing both remote sensing data and analytical framework to provide valuable insight into the temporal dynamics of oil spill contamination in the study area.

LITERATURE REVIEW

The compilation of research examined in this study shows considerable advancements in methodological, as well as the complexities encountered in the context of oil spill investigation, particularly using geospatial technology. Park *et al.*, (2016) examined the oil spill pattern from various types of accidents and contaminants. They utilized temporal, geographical, and spatiotemporal analysis to examine the environmental incidents associated with oil spills that occurred in North Dakota between 2000 and 2014 as a result of the oil boom. Ivanov and Zatyagalova, (2014) mapped oil spills in the marine environment in the Gulf of Thailand, the Caspian Sea, the black sea, and the Sea of Okhotsk using GIS and SAR technologies. In addition, Whanda, *et al.*, (2016) evaluated the geographic cluster and pattern of 443 oil spill incident sites using three geospatial methodologies and ground data. Rajendran *et al.*, (2021) developed an oil spill index by using the spectral band of the sentinel-2, (OSI = (B3+B4)/B2) to map marine oil spills. In addition, they used the drone images from the incident to verify the results of the remote sensing. In Nigeria, relevant studies have been carried out on oil spills, to mention a few; Mohamadi *et al.*, (2016) investigated oil spills' influence on vegetation in Nigeria and it determinants. They made use of ENVL and GIS to produce a multi-endmember spectral mixture analysis (MESMA) model. They were interested in the causes and consequences of vegetation loss brought on by oil spills. While, the research carried out by Balogun *et al.*, (2020) focused on the effect of oil spills and the recovery pattern of wetlands and coastal vegetation by employing multispectral satellite imagery from Landsat and machine learning models. In addition, Dutsenwai *et al.*, (2017) study in Ogoni Land, Rivers State, observed vegetation changes to the intensity of oil spills, by employing statistical methods and remote sensing data (Landsat imageries) for the Normalized Difference Vegetation Index (NDVI).

Synthesizing the collective body of relevant studies, one observes a rich tapestry of methodologies, findings, and scholarly insights. Yet, a focused examination of the integration of remote sensing indices – specifically NDVI, NDWI, LST, and, NDBI – in the context of oil spill impact assessment remains conspicuously absent. This study endeavours to bridge this gap by employing the Analytic Hierarchy Process (AHP) to judiciously assign weights to these indices, reflecting the magnitude and severity of oil spills. The culmination of this methodology is the creation of an innovative oil spill index map, a methodological novelty as per the extant literature. Furthermore, validation against historical data substantiates the accuracy of the index, underscoring the study's contribution towards a more comprehensive and integrated framework for environmental monitoring and oil spill management.

MATERIALS AND METHODS

Study Area

Obio-Akpor Local Government Area (Figure 1) is

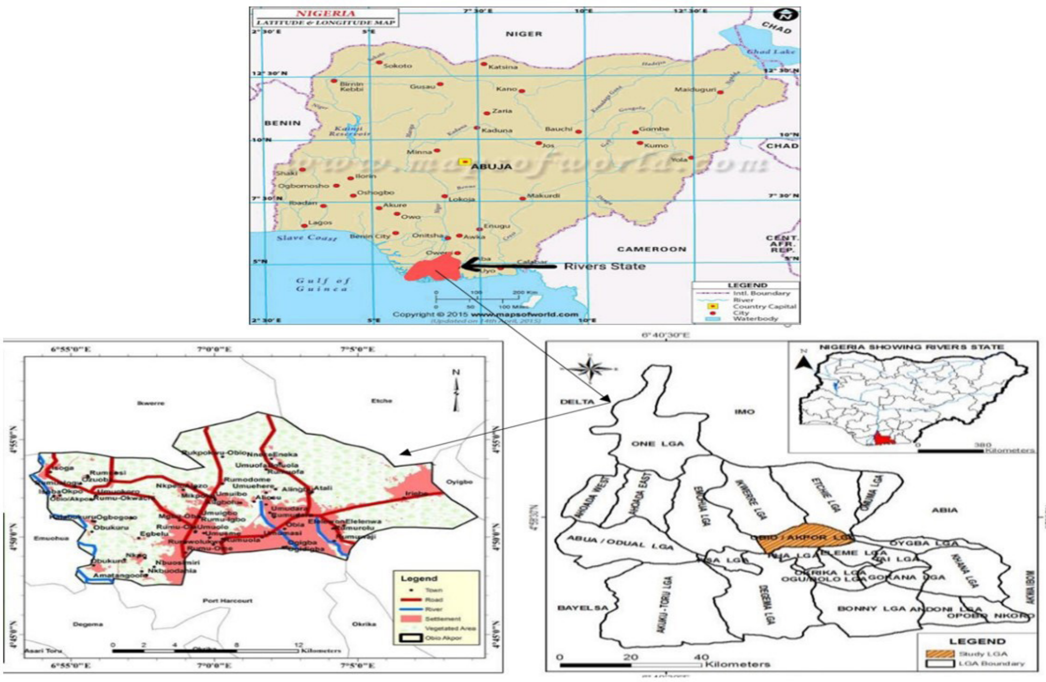

Figure 1: Study Area

situated geographically between Latitudes 4°45'N and 4°55'N and Longitudes 6°55'E and 7°05'E. According to Ayo, *et al.* (2017), Obio/Akpor LGA is bordered to the west by Emohua LGA, to the east by Oyigbo LGA, to the south by Port Harcourt LGA, and to the north by Ikwerre LGA. Obio Akpor LGA is one of the 23 local governments in Rivers State, which is located in what is known as the south southern part of Nigeria, Niger Delta Region. Rumuodu-Maya is home to its administrative center. The Port Harcourt metropolis comprises the LGAs of Eleme, Port Harcourt, and Obio-Akpor (Ayo *et al.*, 2017). Obio-Akpor is one of the four local governments dominated by the Ikwerres. Fishing, farming, lumbering, and hunting are the region's ancestral occupations. It had 464,789 residents in 2006, 487,751 in 2015, and 540,308 in 2020, according to estimates. Construction, engineering, civil service, administration, manufacturing, mining, sand dredging, printing, public service, etc. are among the new occupations that have emerged in this region as a result of greater urbanization brought on by the growing population (Okwakpam & Augustine, 2019). The research area's equatorial location is near the equator, where typical temperatures range from 25 to 28 degrees Celsius and yearly precipitation ranges from 2000 to 2500 millimeters between April and October. Due to its latitudinal location, the region's high temperatures throughout the year generate increased humidity (Eludoyin *et al.*, 2011; Menegbo, 2022). The local vegetation typical of the Niger Delta includes mangrove forests, raffia palm groves, tropical rain forests, and mangrove areas along the shore (Eludoyin et al, 2011; Menegbo, 2022).

Data Collection and Processing

The flowchart of the research methodology is as shown in Figure 2.

The study on oil spills impact assessment employs a comprehensive approach integrating geospatial analysis and remote sensing data. Table I depicts the data acquisition, which involves sourcing information from reputable and reliable sources, covering various aspects relevant to the study, including remote sensing imagery, geographic information, and historical oil spill data. The Landsat imagery covering the year 2003, 2013, and 2023, with a resolution of 30m, was acquired from EarthExplorer Website (http://earthexplorer.usgs.gov/), which is operated by the United States Geological Survey (USGS). The administrative map of the study area was obtained from Rivers State Ministry of Lands and Surveys, which is a governmental department responsible for land management and surveying in the state. The historical oil spill data were gathered from joint investigation reports by Shell Plc, a major oil and gas company operating in the study area. The data source provided the specific URL for accessing spill incident data on Shell's website. This information serves as a crucial dataset for the study, providing valuable insights into the changing landscape and environmental conditions over time.

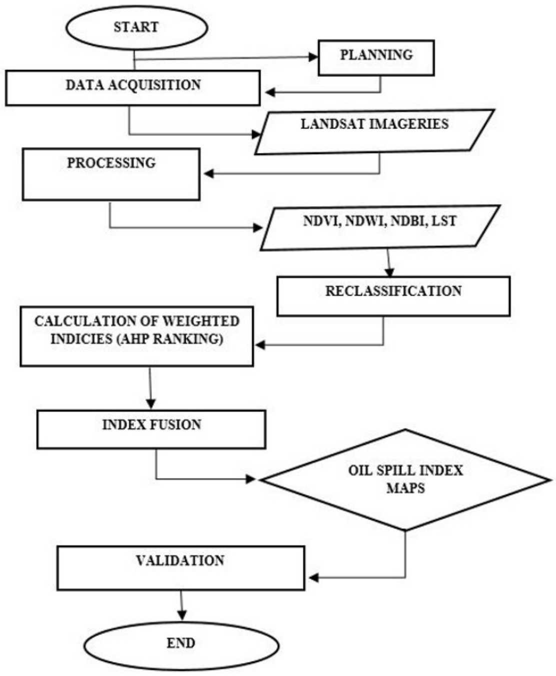

Figure 2: Research methodology flowchart

Table 1: The Adopted Data and their Attributes

S/N	Data	Source	Year	Resolution/Scale	Relevance
1	Landsat Oli/Tm	United States Geological Survey (USGS)	2003	30 m	For remote sensing indices calculation
			2013		
			2023		
2	Administrative map	Rivers state ministry of lands and survey.	2023	1:17000	Extract the boundary of the study area
3	Coordinates of oil spill points in the study area	Shell Plc. Yearly Spill Incident Data	2023	-	For validation of OSI results
			2022		
			2021		
			2020		
			2019		
			2012		

For this study, the various Landsat-7 ETM + and -8 OLI and TIRS spectral bands such as, the red band, green band, NIR band (near-infrared), SWIR band (short-wave infrared) and thermal band (for LST calculation) were used in calculating NDVI, NDWI, LST, and NDBI. The required bands were staked into a single image file using ArcGIS 10.5 software. The quality of data is paramount to ensure the reliability and accuracy of the study findings. Therefore, several steps were undertaken to ensure data quality; atmospheric correction and radiometric calibration were applied to the Landsat imagery to account for atmospheric interference and sensor sensitivity differences. These corrections were essential for accurately representing surface features and conditions. In addition, validations of the results were conducted by comparing the calculated indices with known oil spill incident data. This validation process helped verify the accuracy of the oil spill index map generated from the integration of various remote sensing indices.

The data pre-processing involves a series of steps aimed at preparing the data for analysis and deriving meaningful insights. The pre-processing steps include radiometric calibration, atmospheric correction, masking, and geometric correction.

The processes involve calculating various indices, including Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Built-up Index (NDBI) and Land Surface Temperature (LST). These indices were calculated using appropriate spectral bands and formulas. The calculations are as follows:

NDVI Calculation

NDVI was calculated with the formula:

$$NDVI=(NIR+Red)/(NIR-Red) \quad (1)$$

Where: NIR is the near-infrared band.

Red is the red band.

NDVI values typically range from -1 to 1, with higher values indicating denser and healthier vegetation

NDWI Calculation

NDWI was calculated with the formula:

$$NDWI=(Green+NIR)/(Green-NIR) \quad (2)$$

Where: NIR is the near-infrared band.

Green is the green band.

NDWI values typically range from -1 to 1, with higher values indicating water bodies and lower values indicating non-water features.

NDBI Calculation

NDBI was calculated with the formula:

$$NDBI=(SWIR+NIR)/(SWIR-NIR) \quad (3)$$

Where: SWIR is the short-wave infrared band.

NIR is the near-infrared band.

NDBI values typically range from -1 to 1, with higher values indicating built-up areas and lower values indicating non-built-up areas.

LST Calculation

The thermal infrared bands were used for LST calculation. Landsat 8 and Landsat 7 imagery from 2023, 2013, and 2003 respectively were used to retrieve LST. The thermal infrared bands (Band 10 for Landsat 8 and Band 6 for Landsat 7) were converted to top-of-atmosphere (TOA) during pre-processing. This involved converting the digital numbers to TOA spectral radiance using sensor radiometric calibration coefficients.

Conversion to Brightness Temperature

The TOA spectral radiance values were further processed to obtain brightness temperature (T) using Planck's Law and the thermal band wavelength. The conversion from radiance to brightness temperature was represented by the equation:

$$K_2/\ln(K_1/L_\lambda) \quad (4)$$

Where:

- T is the brightness temperature,
- K2 and K1 are band-specific thermal conversion constants,
- $L\lambda$ is the TOA spectral radiance.

Deriving Land Surface Emissivity (LSE)

The calculation of land surface emissivity (LSE) is critical to LST retrieval and was performed using the following equations:

$$Pv=((NDVI-NDVImin)/(NDVImax-NDVImin))^2 \quad (5)$$

Subsequently, the land surface emissivity (e) was calculated using

$$e=0.004\times Pv+0.986 \quad (6)$$

This step is crucial in refining the accuracy of LST retrieval.

Conversion of LST from Kelvin to Degree Celsius

After the emissivity-corrected land surface temperatures were estimated in degrees Kelvin, the values were converted to degrees Celsius for easy comprehension. This conversion was achieved using the relation

$$LST(°C)=LST(K)-273.15 \quad (7)$$

Reclassification and Weight Assignment

Reclassification and weight assignment are crucial steps in data processing, aimed at standardizing scales and assigning weights to different indices. This involves converting the continuous values of the indices into discrete classes and categories. These classes (NDVI, NDWI, NDBI, and LST) were assigned ranks ranging from 1 to 5 (low to high) based on their sensitivity to oil spills, with higher ranks indicating greater sensitivity. Weight assignment was done using Analytical Hierarchy Process (AHP) method, which compares the importance of different criteria relative to each other. This comparison was made using Saaty's 9-point scale (Figure 3)

Scale	Judgment of preference	Description
1	Equally important	Two factors contribute equally to the objective
3	Moderately important	Experience and judgment slightly favour one over the other
5	Important	Experience and judgment strongly important favour one over the other
7	Very strongly important	Experience and judgment strongly important favour one over the other
9	Extremely important	The evidence favouring one over the other is of the highest possible validity
2, 4, 6, 8	Intermediate preference between adjacent scales	When compromised is needed.

Figure 3: Saaty scale for various elements comparison
Source: Saaty (1980)

As part of the AHP process, the raw comparison matrix was normalized to derive ratio scale priority vectors. Normalization was achieved by dividing each value in a criterion's column by the sum of the column. This converted the comparisons to a proportional ratio scale while maintaining their relativity. The normalization process was applied to each column of the comparison matrix. It enabled priority vectors to be extracted that represented the relative weights or priorities of each criterion proportional to the others.

The normalized comparison matrix retained the original criteria relationships while transforming values to a 0 to 1 scale suitable for quantifying the relative importance or weight of each factor in the suitability analysis.

Formula:

- Nij is the normalized value for the comparison between criterion i and criterion j.
- n is the number of criteria.

Consistency Table

The consistency of judgments in the AHP comparison matrix was evaluated to ensure logical, high-quality criteria weights. Consistency was measured by first calculating a consistency index (CI) for the matrix. CI indicates the level of consistency in the comparisons, with lower values being more consistent.

CI was compared to a random index (RI) based on the number of criteria, to derive a consistency ratio (CR). Saaty established that CR should be less than 0.1 to indicate acceptable consistency.

A consistency table was generated showing the CI, RI and CR values. If CR exceeded 0.1, the most inconsistent judgments were identified and the comparisons were revised to improve consistency.

This consistency evaluation ensured that irrational or random comparisons did not propagate into the final AHP weights. Logical, high-quality judgments translated to reliable, data-driven criteria priorities for the suitability analysis. The consistency table provided quantitative verification that the AHP process produced a consistent, robust weighting of factors for the oil spill index map.

$$\sum^{n}_{(j=1)} (N_{ij} * Weight_j) \quad (8)$$

- Weighted Sum Value i: Weighted sum for criterion i.
- Nij: Normalized value for the pairwise comparison between criteria i and j.
- Weight j: Weight for criterion j.
- n: Number of criteria.

principal eigenvalue (λmax) =

$$\frac{\frac{Sum(Weigthed\ Sum\ of\ each\ Criterion)}{Normalized\ Weight}}{n} \quad (9)$$

$$C.I = (\lambda max - n)/(n-1) \quad (10)$$

C.I: Consistency Index.

λmax: Principal eigenvalue of the matrix.

n: Number of criteria.

Formula: $C.R = (C.I)/(R.I)$ (11)

Table 2: Random index matrix of the same dimension (Saaty 1980)

"Number of criteria"	2	3	4	5	J	7	8	9	10	11
R1	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.5

Integration of Indices and Validation

This involves combining the normalized indices using a weighted summation approach to create a composite Oil Spill Index (OSI) as seen in (equation 12). Each index was multiplied by its corresponding weight, and the results were summed to obtain the OSI. This composite index represents the oil spill potential for different years, providing valuable insights into areas prone to oil spill.

$$OSI = wNDVI \times NDVI + wNDWI \times NDWI + wLST \times LST + w\,NDBI \times NDBI \quad (12)$$

Where:

wNDVI, wNDWI, wLST, and wNDBI are the weights assigned to each index.

NDVI, NDWI, LST, and NDBI are the normalized values of NDVI, NDWI, LST, and NDBI, respectively.

The OSI was validated against historical oil spill incident points obtained from Shell Plc. This validation process ensures spatial alignment between the oil spill index map and historical oil spill incident data, helping verify the accuracy of the index in predicting and identifying areas prone to oil spills.

RESULT AND DISCUSSION

Results Analysis

The results of NDVI, NDWI, LST, and NDBI for the years 2003, 2013 and 2023 were presented and analysed. The study further presented the result of the AHP weighed indices based on their sensitivity to oil spills and integrated them into a comprehensive oil spill index. In addition, the validation of the oil spill index was done against historical oil spill incident data.

Normalized Difference Vegetative Index (NDVI)

Figures 4, 5, and 6 present the Normalized Difference Vegetation Index (NDVI) maps for the years 2003, 2013, and 2023. While figure 6 and 8 are the charts revealing notable trends in vegetation health and density. In 2003, NDVI values ranged from -0.12 to 0.68, expanding to -0.19 to 0.76 in 2013, and narrowing to -0.17 to 0.63 in 2023.

Low NDVI values suggest sparse or stressed vegetation, while high values indicate dense and healthy vegetation. Consistent dense vegetation was observed in the western part of the study area across all three years, contrasting with a decline in vegetation cover in the eastern part, which happens to be the part where most oil spill incidents occurred in the study area, particularly between 2013 and 2023. Analysis shows a general decrease in NDVI from 2003 to 2023, emphasizing the environmental impacts of oil spills.

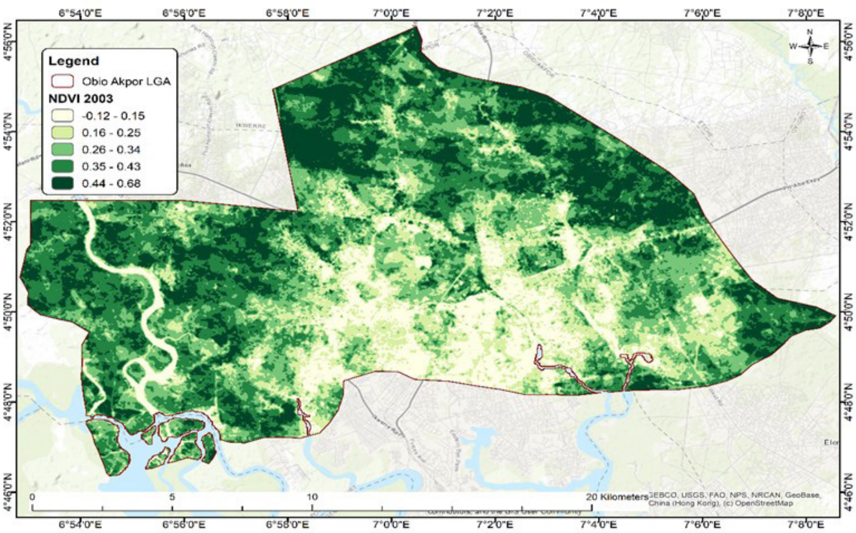

Figure 4: 2003 Normalize Difference Vegetative Index (NDVI)

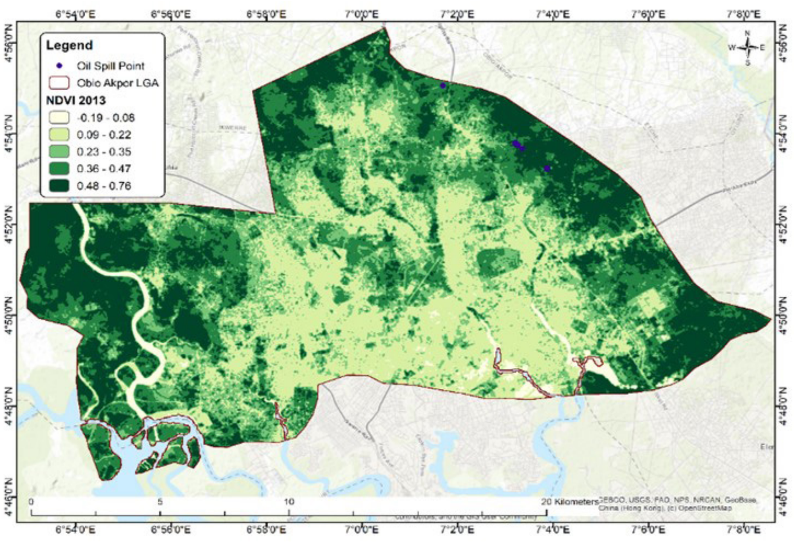

Figure 5: 2013 Normalize Difference Vegetative Index (NDVI)

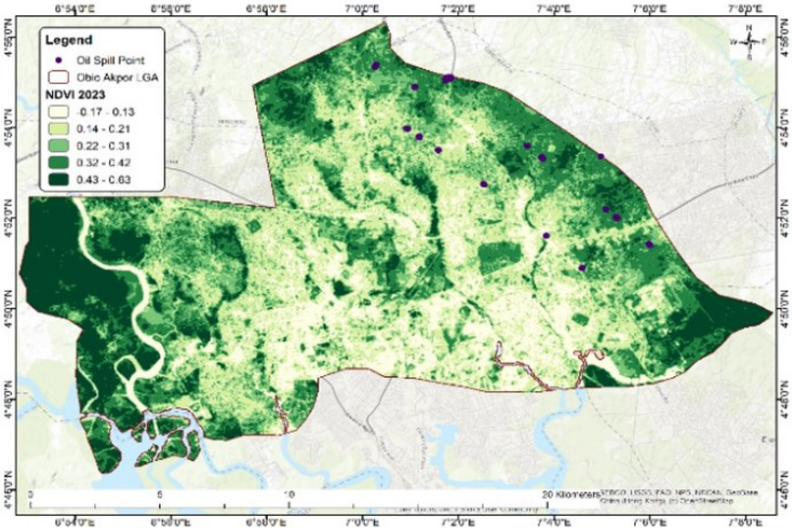

Figure 6: 2023 Normalize Difference Vegetative Index (NDVI)

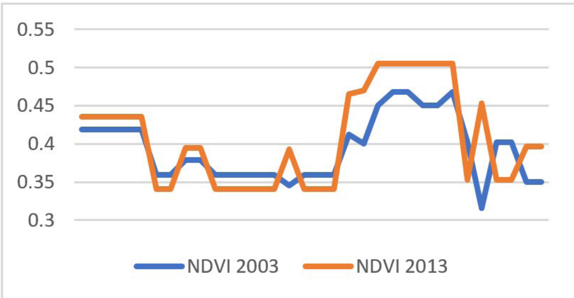

Figure 7: Changes in NDVI between Years 2003 and 2013

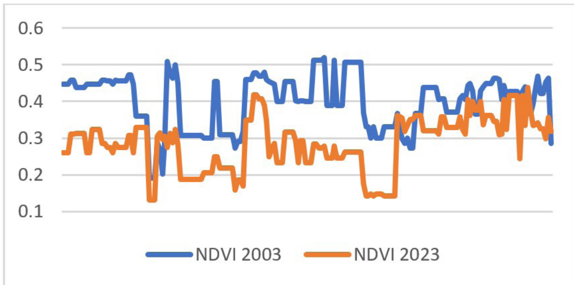

Figure 8: Changes in NDVI between Year2003 and 2023

Normalized Difference Water Index (NDWI)

The NDWI maps in Figure 9, 10, and 11 show changes in water content for 2003, 2013 and 2023. The NDWI ranges vary over the years: from -0.56 to 0.19 in 2003, -0.64 to 0.31 in 2013, and -0.52 to 0.29 in 2023. Lower values indicate less water, while higher values suggest more water or moist vegetation. Figure 12 and 13 shows the NDWI chart. Fluctuations in NDWI may result from water contamination due to oil spills.

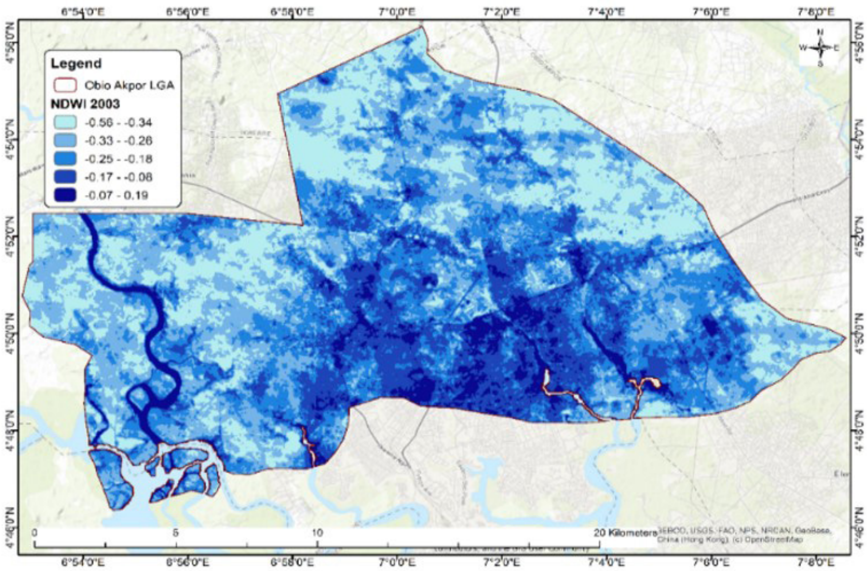

Figure 9: 2003 Normalize Difference Water Index (NDWI)

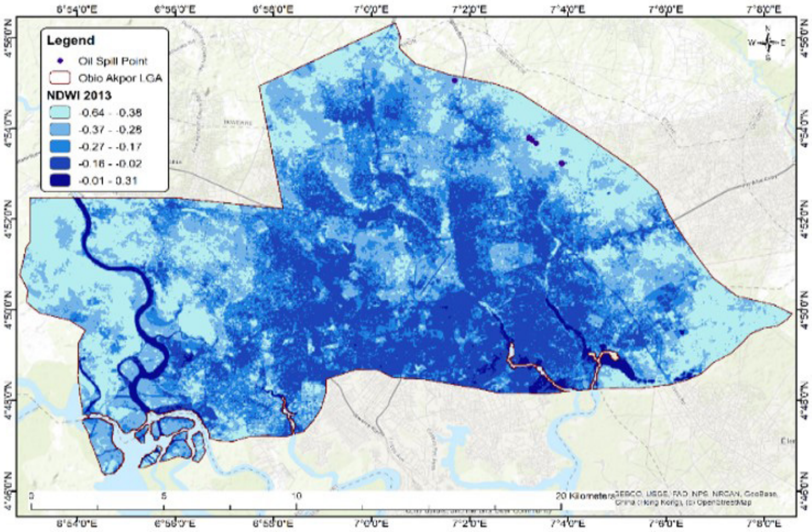

Figure 10: 2013 Normalize Difference Water Index (NDWI)

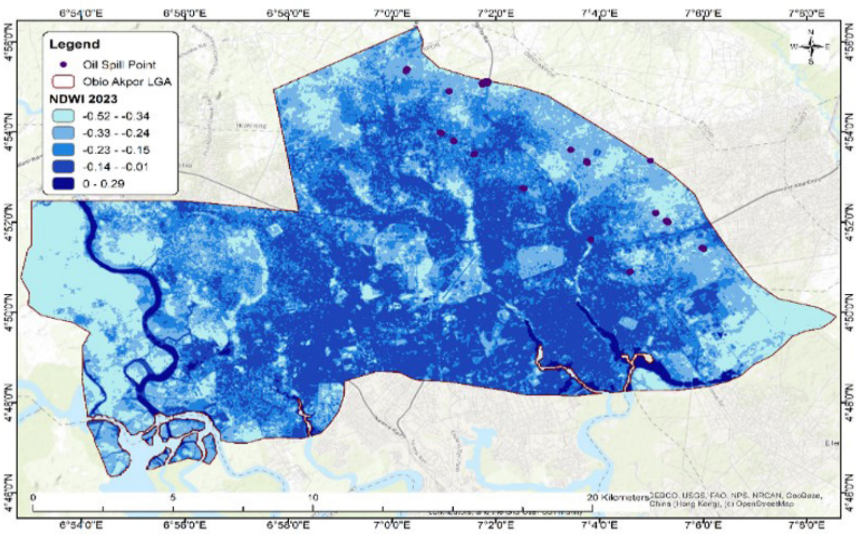

Figure 11: 2023 Normalize Difference Water Index (NDWI)

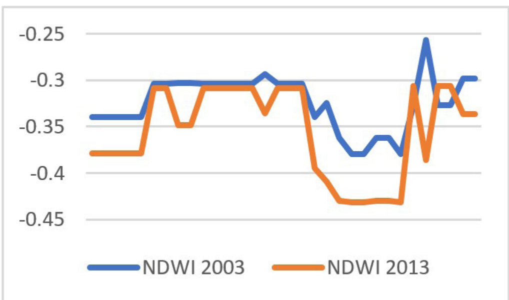

Figure 12: Changes in NDWI between Years 2003 and 2013

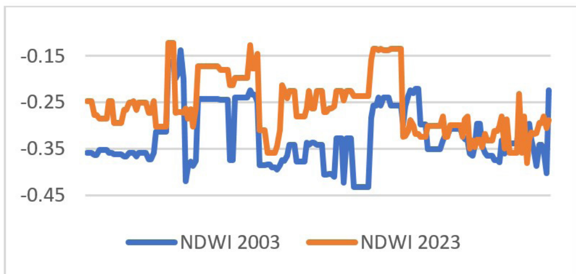

Figure 13: Changes in NDWI between Years 2003 and 2023

Normalized Difference Built-Up Index (NDBI)

Figure 14, 15, and 16 depict the Normalized Difference Built-up Index (NDBI) maps for the years 2003, 2013, and 2023, respectively. In 2003, NDBI values ranged from -0.48 to 0.39, followed by -0.48 to 0.29 in 2013, and -0.44 to 0.31 in 2023. High NDBI values indicate a high concentration of built-up areas. Figure 17 and 18 shows the NDBI chart. Conversely, areas with lower NDBI values represent a lower concentration of built-up areas. The NDBI value ranges provide valuable insights into changes in built-up areas and their sensitivity to oil spills over time.

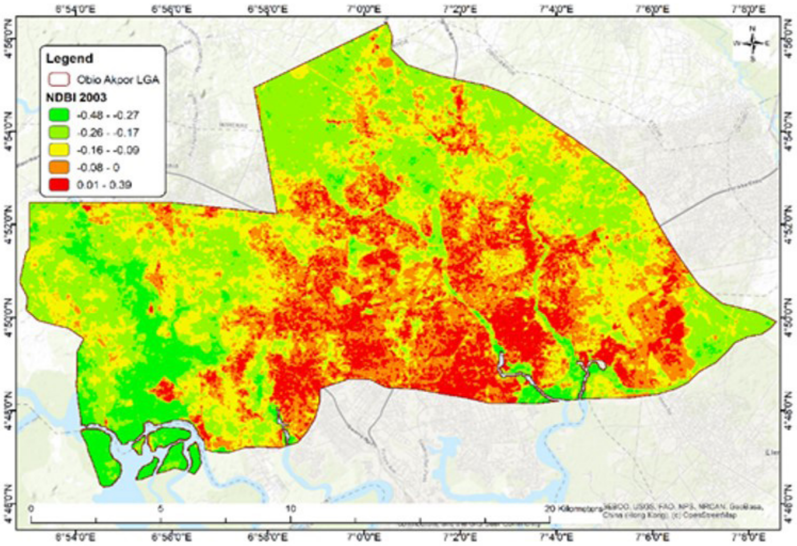

Figure 14: 2003 Normalize Difference Built-Up Index (NDBI)

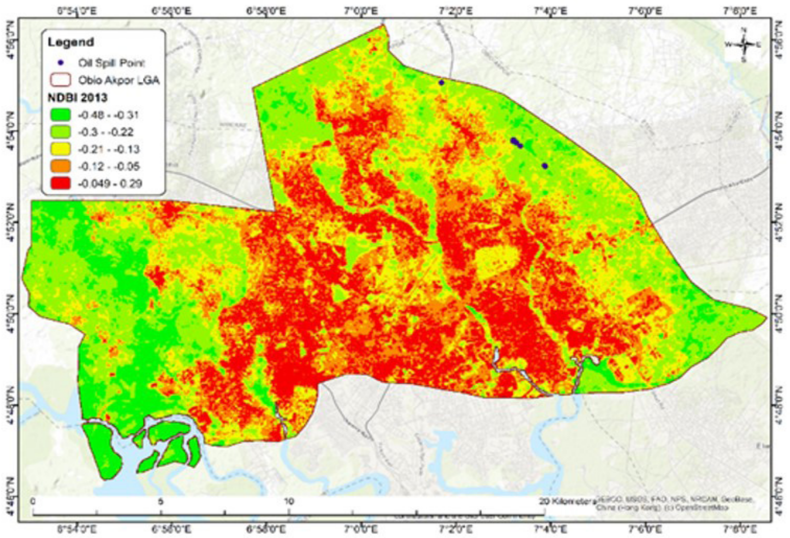

Figure 15: 2013 Normalize Difference Built-Up Index (NDBI)

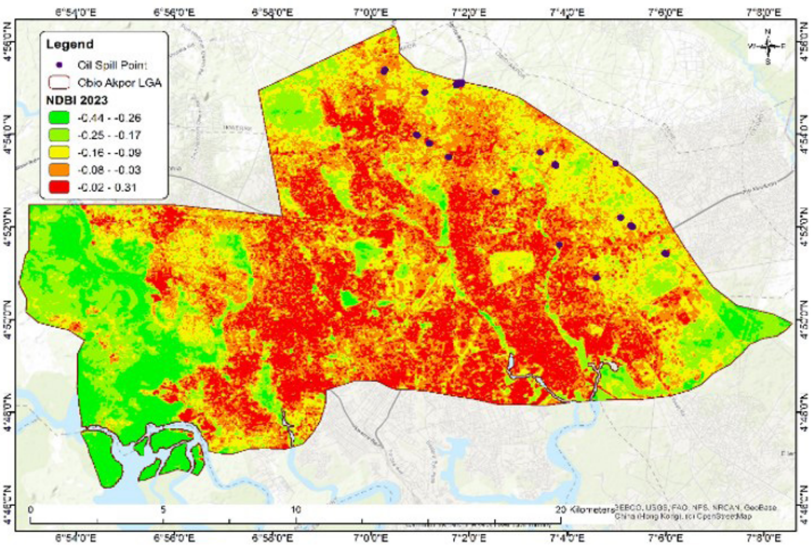

Figure 16: 2023 Normalize Difference Built-Up Index (NDBI)

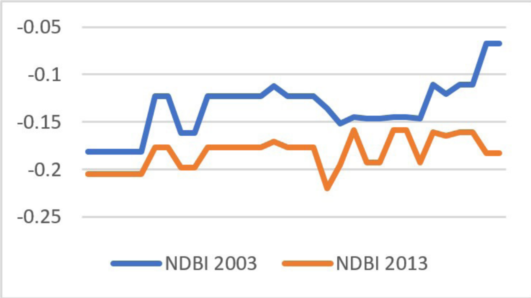

Figure 17: Changes in NDBI between Years 2003 and 2013

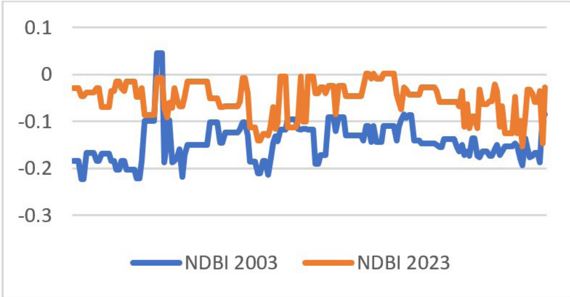

Figure 18: Changes in NDBI between Years 2003 and 2023

Land Surface Temperature (LST)

Figure 19, 20, and 21 illustrate the Land Surface Temperature (LST) variations across the study area for the years 2003, 2013, and 2023. In 2003, LST values ranged from 17.63 to 31.78°C, expanding to 20.07 to 34.21°C in 2013, and then narrowing to 18.52 to 30.4°C in 2023. Built-up areas consistently exhibit high LST values throughout the study period, indicating urban heat island effects. Figure 22 and 23 shows the LST charts. Conversely, areas with dense vegetation and water bodies show lower LST values due to shading and evaporative cooling effects. Analysis of oil spill points reveals an increase in LST values for the affected areas in both 2013 and 2023, suggesting potential impacts of oil contamination on surface temperatures.

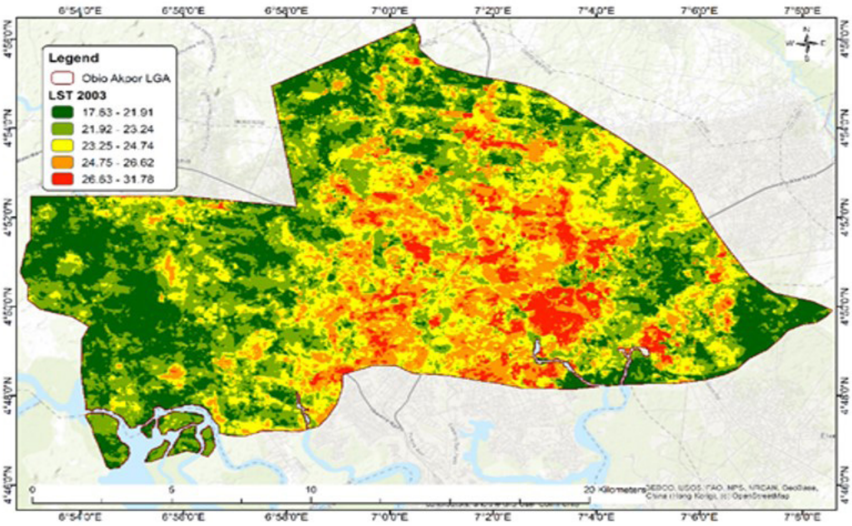

Figure 19: 2003 Land Surface Temperature (LST)

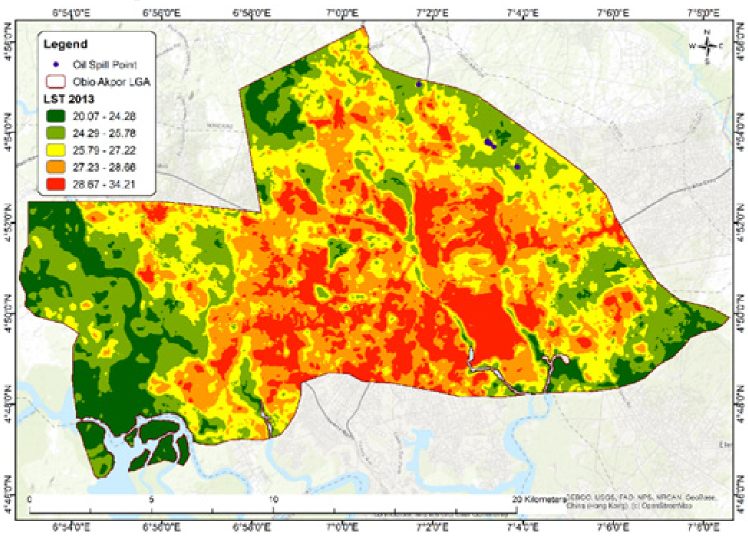

Figure 20: 2013 Land Surface Temperature (LST)

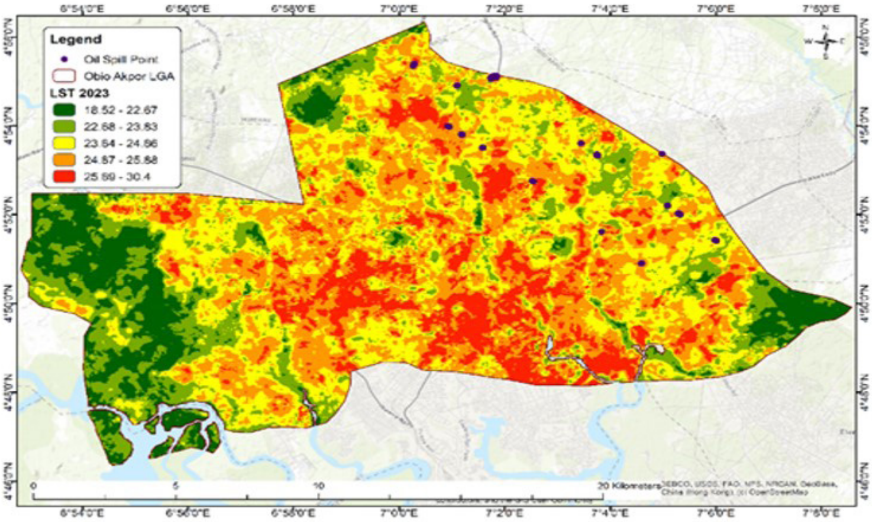

Figure 21: 2023 Land Surface Temperature (LST)

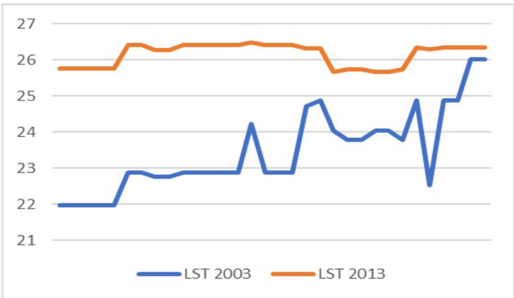

Figure 22: Changes in LST for Years 2003 and 2013

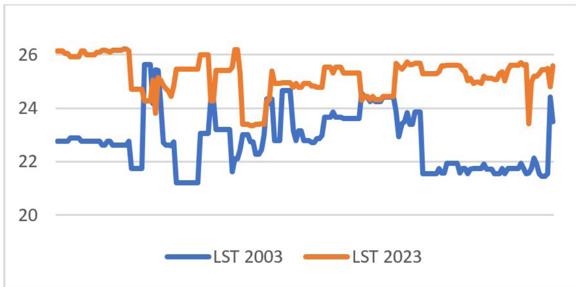

Figure 23: Changes in LST for Years 2003 and 2023

Analytical Hierarchy Process (AHP)

The AHP results show NDVI as most influential with a weight of 0.52, followed by NDWI and LST, each at 0.20, and NDBI at 0.08. NDVI's prominence underscores vegetation's role in oil spill impacts. NDWI and LST carry equal weight, acknowledging their joint importance. NDBI, representing built-up areas, receives the lowest weight, reflecting its lesser impact compared to vegetation, water, and temperature. However, NDBI's inclusion is still crucial for addressing urban vulnerabilities to oil spills. The AHP matrix table, the normalized matrix table, and consistency table is depicted in Table III, IV, and V respectively.

Table 3: AHP Matrix Table

PAIRWISE	NDVI	NDWI	NDBI	LST	
NDVI	1	3	5	3	3.00
NDWI	1/3	1	3	1	1.33
NDBI	1/5	1/3	1	1/3	0.47
LST	1/3	1	3	1	1.33
	1.87	5.33	12.00	5.33	

Source : Author

Table 4: Normalized Matrix

NORMALIZED	NDVI	NDWI	NDBI	LST	WEIGHT
NDVI	0.54	0.56	0.42	0.56	0.52
NDWI	0.18	0.19	0.25	0.19	0.20
NDBI	0.11	0.06	0.08	0.06	0.08
LST	0.18	0.19	0.25	0.19	0.20
SUM					1.00

Source : Author

Table 5: Consistency Table

CONSISTENCY	NDVI	NDWI	NDBI	LST	WEIGHTED SUM	
NDVI	0.52	0.60	0.39	0.60	2.12	4.08
NDWI	0.17	0.20	0.24	0.20	0.81	4.04
NDBI	0.10	0.07	0.08	0.07	0.32	4.02
LST	0.17	0.20	0.24	0.20	0.81	4.04

Source : Author

Reclassification Result Based on the Assigned Weights

Since LST has a different measurement range and units from NDVI, NDWI and NDBI reclassification was done to harmonize all the factors by converting them into common classes or categories. The reclassification maps provide a

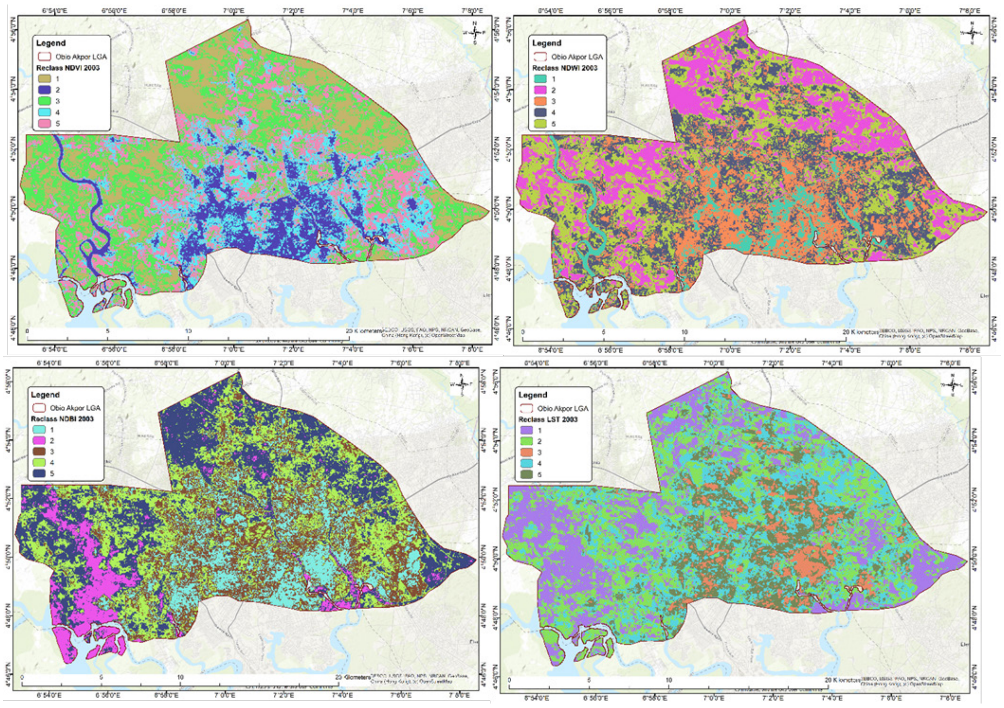

Figure 24: 2003 Reclassified Maps of NDVI, NDWI, NDBI and LST

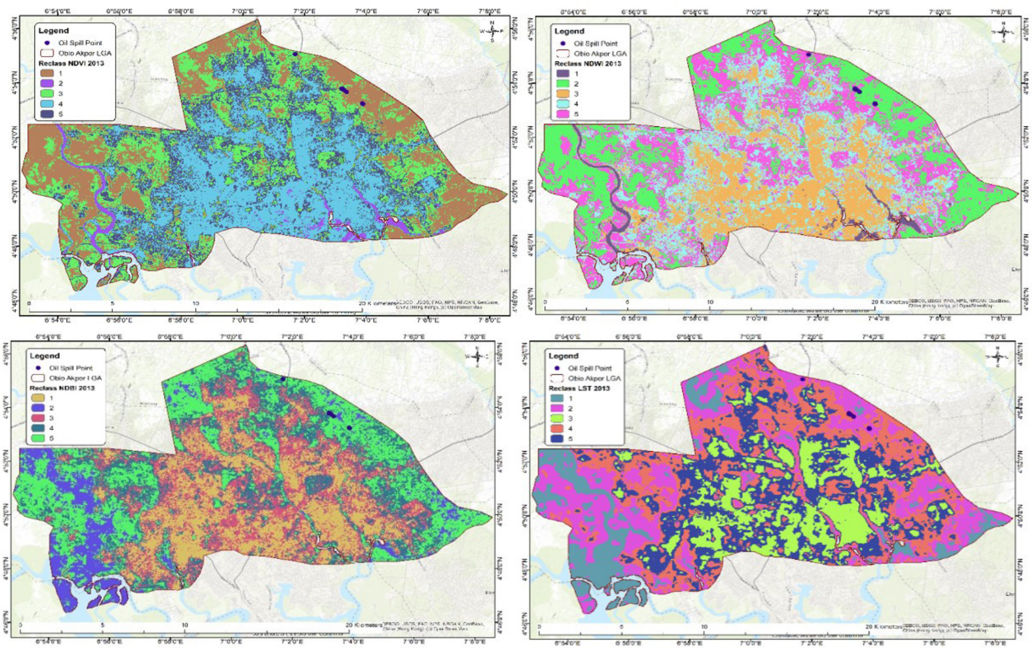

Figure 25: 2013 Reclassified Maps of NDVI, NDWI, NDBI and LST

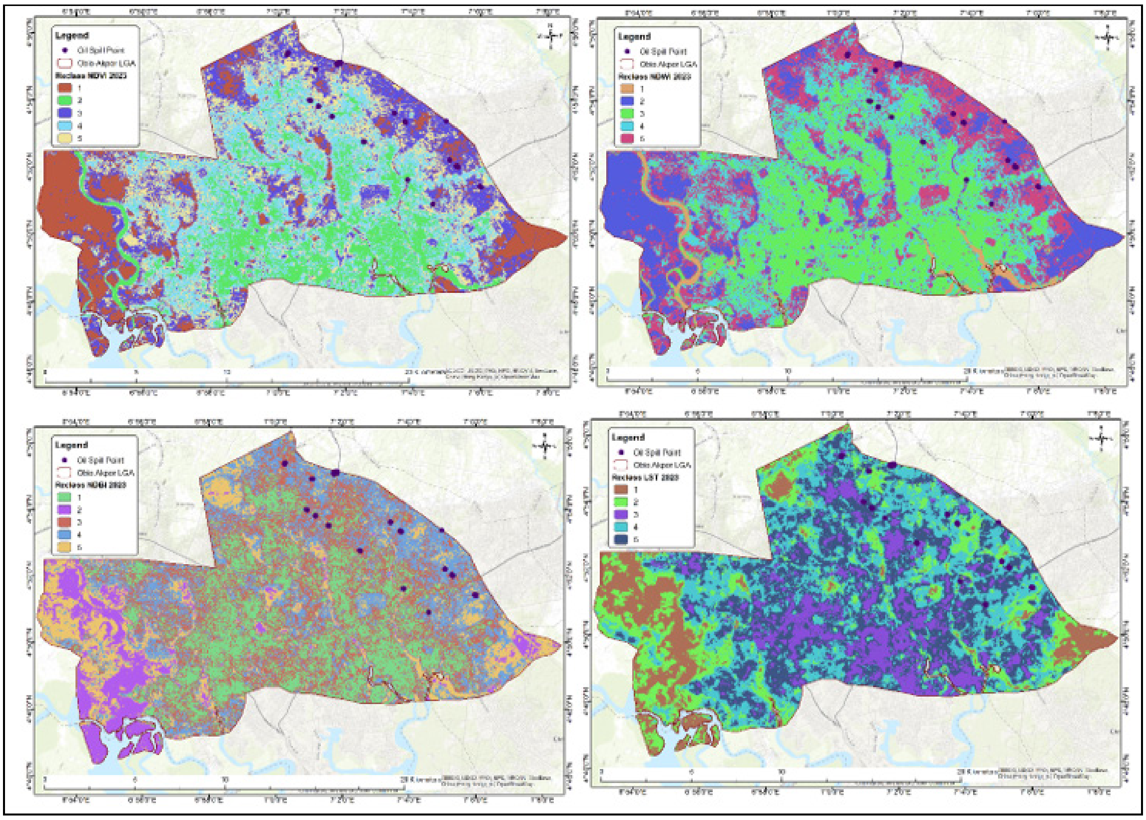

Figure 26: 2023 Reclassified Maps of NDVI, NDWI, NDBI and LST

comprehensive overview of the spatial distribution of these key indices within the study area. Each index was carefully categorized into five distinct levels, ranging from 1 to 5, based on their respective value ranges which represent very low to very high. The reclassification results are presented in maps as shown in Figure 24 to 26.

Oil Spill Index Map

The observed trends in the oil spill index (Figure 27 to 31) between the years 2003 to 2013 and 2003 to 2023 reveal significant changes in oil spill susceptibility over time. The chart depicting the oil spill index between 2003 and 2013 shows a mix of increases and a little decrease in oil spill susceptibility across different regions. The chart illustrating the oil spill index trend from 2003 to 2023 indicates a substantial increase in the oil spill index over the two-decade period. This drastic rise in the oil spill index suggests a worsening of environmental conditions or an escalation in factors contributing to oil spill risks across the study area.

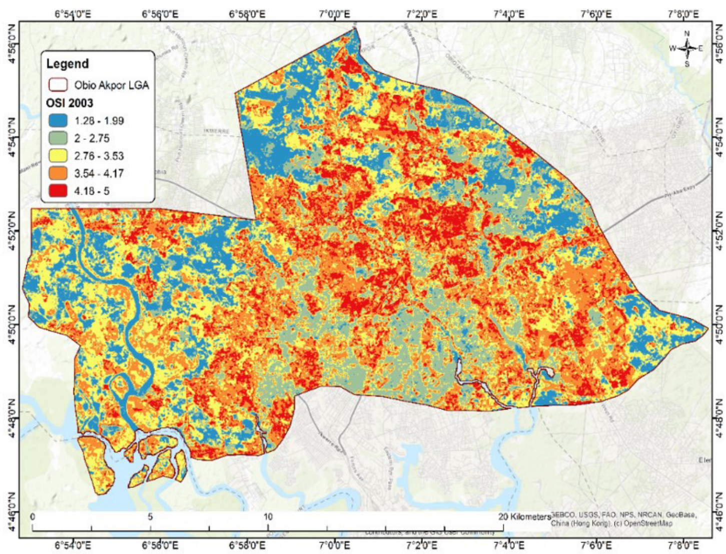

Figure 27: 2003 Oil Spill Index Map

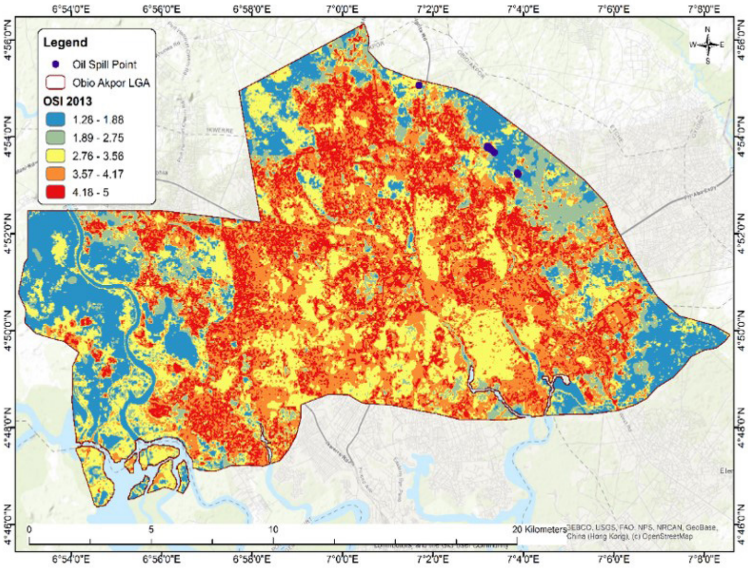

Figure 28: 2013 Oil Spill Index Map

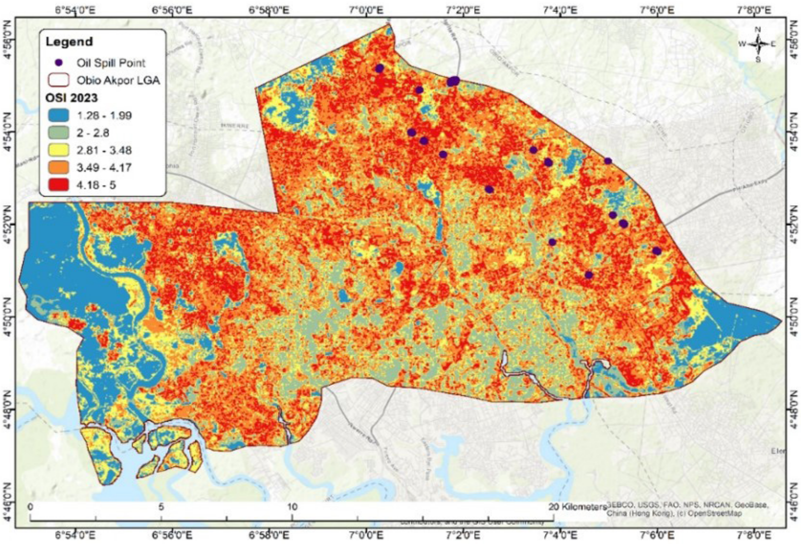

Figure 29: 2023 Oil Spill Index Map

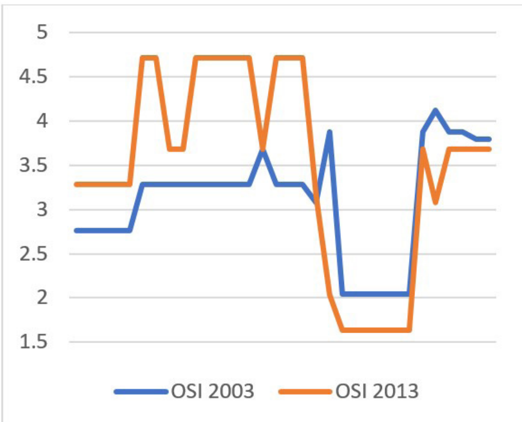

Figure 30: Chart Showing Changes in OSI between Year 2003 and 2013

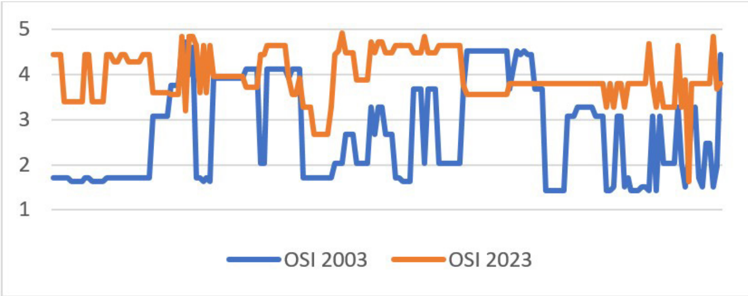

Figure 31: Chart Showing Changes in OSI of Year 2003 and 2023

Validation of Oil Spill Index

The finding of higher and increased oil spill index values corresponding to the locations of historical oil spill incidents provides valuable validation of the effectiveness of the analysis of the oil spill index performed through the integration of AHP-weighted NDVI, NDWI, NDBI, and LST. The tables VI to VII show the OSI of the points before the oil spill incident (2003) and after the spill incident (2013 and 2023)

Validation of Oil Spill Index in 2003 and 2013

In 2003, the OSI values ranged from 1.04 to 3.48 across different points, indicating varying degrees of oil contamination before the spill incident. After the incident in 2013, there was a noticeable increase in OSI, with values ranging from 3.08 to 4.72 at the spill points. This suggests a worsening of the oil spill's impact on the affected areas.

Table 6: 2003 and 2013 validation Result

Fid	Shape	Date	Community	Latitude	Longitude	OSI 2003	OSI 2013
0	Point	17th-25th Aug. 2012	Eneka	4.917683	7.028221	2.76	3.28
1	Point		Eneka	4.91769	7.028196	2.76	3.28
2	Point		Eneka	4.917718	7.02823	2.76	3.28
3	Point		Eneka	4.917679	7.028259	2.76	3.28
4	Point		Eneka	4.917641	7.028215	2.76	3.28
5	Point	23rd-26th July 2012	Eneka	4.896433	7.053776	2.28	4.72
6	Point		Eneka	4.896405	7.053804	3.27	4.72
7	Point		Eneka	4.896489	7.053832	3.28	3.68
8	Point		Eneka	4.896489	7.053777	2.54	3.68
9	Point		Eneka	4.89635	7.053804	3.48	4.66
10	Point		Eneka	4.89635	7.05386	3.28	4.72
11	Point		Eneka	4.896295	7.053887	3.28	4.72
12	Point		Eneka	4.896294	7.053832	3.28	4.72
13	Point		Eneka	4.896295	7.053915	3.28	4.72
14	Point		Eneka	4.896267	7.053389	3.28	3.68
15	Point		Eneka	4.896239	7.053915	3.28	4.72
16	Point		Eneka	4.896267	7.053943	3.28	4.72
17	Point		Eneka	4.896239	7.053944	3.28	4.72
18	Point		Eneka	4.896017	7.054221	3.08	3.16
19	Point		Eneka	4.895739	7.05461	3.28	4.04
20	Point	27th -29th July 2012	Atali	4.88704	7.06475	1.04	3.64
21	Point		Atali	4.88746	7.064469	1.04	3.64
22	Point		Atali	4.887405	7.064527	1.04	3.64
23	Point		Atali	4.887099	7.064721	1.04	3.64
24	Point		Atali	4.887183	7.064693	1.04	3.64

Validation of Oil Spill Index in 2003 and 2023

The 2003 and 2023 OSI validation table provides the Oil Spill Index (OSI) values of various points before and after an oil spill incident, specifically comparing the OSI values from 2003 to those in 2023. In 2003, the OSI values varied across different points, ranging from 1.64 to 3.72, indicating varying degrees of oil contamination before the spill incident.

After the incident in 2023, there is a noticeable change in OSI values, with values ranging from 3.2 to 4.84. This suggests a potential increase in the impact of the oil spill on the affected areas over the years.

Table 7: 2003 and 2023 validation Result

Fid	Shape	Date	Community	Latitude	Longitude	OSI 2003	OSI 2023
1	Point	19th - 20th Dec. 2022	Rumukwurushi	4.86697	7.08829	1.72	4.44
2	Point		Rumukwurushi	4.86692	7.08836	1.72	4.44
3	Point		Rumukwurushi	4.86688	7.08829	1.72	4.44
4	Point		Rumukwurushi	4.86697	7.08812	1.72	3.4
5	Point		Rumukwurushi	4.86705	7.08805	1.72	3.4
6	Point		Rumukwurushi	4.86713	7.0881	1.64	3.4
7	Point		Rumukwurushi	4.86658	7.08869	1.72	4.28
8	Point		Rumukwurushi	4.86664	7.08865	1.72	4.28
9	Point	27th -30th Sept. 2022	Eneka	4.89337	7.05743	3.08	3.6
10	Point		Eneka	4.89336	7.0574	3.08	3.6
11	Point		Eneka	4.89347	7.05734	3.08	3.6
12	Point		Eneka	4.89343	7.05743	3.08	3.6
13	Point		Eneka	4.89339	7.05746	3.08	3.6
14	Point	3rd - 10th Jan. 2023	Rumukwurushi	4.86027	7.06392	3.76	3.56
15	Point		Rumukwurushi	4.8603	7.06391	3.76	3.56
16	Point		Rumukwurushi	4.86018	7.06394	3.76	3.56
17	Point	3rd-4th Dec 2021	Eneka	4.91514	7.01834	3.6	4.84
18	Point		Eneka	4.91501	7.01815	2.72	3.2
19	Point		Eneka	4.91509	7.01813	3	4.84
20	Point		Eneka	4.91511	7.01842	3.6	4.84
21	Point	26th-27th Feb 2020	Atali	4.88889	7.06267	1.72	4.64
22	Point		Atali	4.88891	7.06235	1.72	3.6
23	Point		Atali	4.88931	7.06243	1.64	4.64
24	Point		Eneka	4.89971	7.01572	3.92	3.96
25	Point		Eneka	4.8997	7.01571	3.92	3.96
26	Point		Eneka	4.89971	7.01564	3.92	3.96
27	Point		Eneka	4.89968	7.01564	3.12	3.72
28	Point		Eneka	4.89966	7.01568	3.12	3.72
29	Point		Eneka	4.89965	7.01568	3.12	3.72
30	Point		Eneka	4.89968	7.01562	3.12	3.72
31	Point		Rumuewhara	4.87912	7.04243	2.04	4.44
32	Point		Rumuewhara	4.87908	7.04239	2.04	4.44
33	Point	2nd May 2020	Elelenwo	4.848219	7.076442	3.12	4.64
34	Point		Elelenwo	4.848222	7.076459	3.12	4.64
35	Point		Elelenwo	4.84844	7.076592	3.12	4.64
36	Point		Elelenwo	4.848459	7.076565	3.12	4.64
37	Point		Elelenwo	4.848456	7.076481	3.12	4.64
38	Point		Elelenwo	4.848299	7.076389	3.12	4.64
39	Point		Elelenwo	4.848203	7.076414	3.92	3.92
40	Point		Rumuowha	4.899843	7.015256	3.12	3.56

41	Point		Rumuowha	4.899748	7.015351	3.12	3.56
42	Point		Rumuowha	4.89955	7.01582	3.12	3.92
43	Point	15th -20th June 2020	Rumuokwurusi	4.86997	7.08475	1.72	3.28
44	Point		Rumuokwurusi	4.86995	7.08482	1.72	3.28

CONCLUSION

The study comprehensively analyzed the impact of oil spills on the study area's environment by examining the temporal dynamics of key indices (NDVI, NDWI, LST, and NDBI) and integrating them to create an Oil Spill Index (OSI) map. To determine the relative significance of each criterion, the Analytical Hierarchy Process (AHP) method was employed, assigning weights to the indices. NDVI emerged as the most influential criterion, followed by NDWI and LST, while NDBI had the lowest weight. This weighting system highlighted NDVI's predominant role in expressing the extent and severity of oil spills in the area. Upon reclassification and integration of the indices, the generated OSI map revealed a concerning trend of increasing oil spill susceptibility from 2003 to 2023. The validation of the OSI maps against historical oil spill records further affirmed their accuracy and predictive capability in identifying areas prone to oil spills. Through meticulous examination spanning from 2003 to 2023, significant changes in index ranges were observed, indicating dynamic environmental shifts. For instance, OSI values for 2003 and 2013, indicated a range of 1.04 to 3.48 for 2003, with a noticeable increase observed in 2013, expanding the range to 3.08 to 4.72. Similarly, a comparison of OSI values between 2003 and 2023 indicated OSI values, ranging from 1.64 to 3.92 in 2003, then in 2023 after the oil spill incidents, there were notable changes in the OSI values, with the range shifting to 3.2 to 4.84. This escalation in the OSI values suggests worsening environmental conditions and heightened oil spill risks across the study area.

Finally, the study emphasizes the critical importance of ongoing monitoring and mitigation efforts in addressing the evolving environmental challenges posed by oil spills. By providing comprehensive insights into the temporal dynamics and spatial distribution of oil spill impacts, the research serves as a valuable resource for policymakers and stakeholders involved in environmental management and disaster response initiatives.

RECOMMENDATION

Based on the findings and conclusions drawn from this research, this study is recommended as valuable information for monitoring and assessing the environmental impact of oil spills as it shows the likelihood of the study area being damaged by oil spills as the year progresses. In addition, while the current research focuses on the integration of environmental indices, future studies should consider incorporating socio-economic factors to provide a more holistic understanding of oil spill risks. This may include factors such as population density, infrastructure vulnerability, economic activities, and community resilience, which play a significant role in shaping the impacts and responses to oil spills.

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