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RESEARCH ARTICLE

Exposure, geochemical, and spatial distribution patterns of an oil spill in parts of the Niger Delta Region of Nigeria

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Abstract: Large-scale and small-scale spilt oil is as old as exploration activities in the Niger Delta region of Nigeria. There is a need to provide the exposure, geochemical and spatial characteristics in the Niger Delta Region of Nigeria because of the effects of the spilt oil on the communities and the environment. Some of the spilt oil-disaster impacts for exposed communities include psychological effects and socio-demographic characteristics. In this study, the characteristics, sources, spatial and socio-demographic risk predictions of the spilt oil discovered by Kolo Creek coastal residents are examined. A random sample of 900 residents of Kolo Creek coastal communities included exposure characteristics linked to health, the social and economic lifestyle of the communities. The demographic characteristics included age, gender, literacy, and occupation as covariates in the analyses. Respondents provided varied information on the amount of health, the social, and economic impacts. The highest and lowest direct exposure impact accounts 94.65±2.0% and 5.95±1.52% for smoggy weather and obstruction to watercourses respectively. The geochemical distribution pattern was examined using standard laboratory procedures. This investigation included the determination of the physical and chemical characteristics of water samples at the oil spill sites. Also, the biochemical oxygen demand (BOD), chemical oxygen demand (COD), total hydrocarbon content (THC), and total petroleum hydrocarbon (TPH) of both water and sediment samples were carried out. A strong correlation exists between these parameters (*i.e.* at $p < 0.01$) and indicate communalities greater than 0.5. The pollution distribution maps support the spatial distribution pattern and correlate significantly ($p < 0.01$) with the exposure distribution, and the geochemical distribution patterns.

Keywords: spilt oil, three-tier characteristics, total hydrocarbon content, total petroleum hydrocarbon, Niger Delta

1 Introduction

An oil spill is considered a marine pollutant of global interest [1]. Large-scale and small-scale oil spills are as old as exploration activities in the Niger Delta region of Nigeria. Despite the presence of the National Oil Spill Detection and Response Agency since 2006 (NOSDRA), oil production in Nigeria and the Niger Delta region, in particular witnessed some setbacks for over a decade. There is an increase in oil exploration and its attendance degradation of the environment in the Niger Delta region of Nigeria [1]. Therefore, there is an increased risk of oil pollution in the region, linked with accidental pipeline breakage, deliberate pipeline breakage or a combination of both.

There are various causes of the spilt oil in the Niger Delta region of Nigeria since this region is dotted with several oil pipelines. Oil spill from these pipelines is either accidental or deliberate or a combination of both. The accidental oil spill is due to the breakage of ageing pipelines. Deliberate destruction of oil pipelines is caused by oil scavengers also known as bunkering. In both cases, oil is spilt into the environment, thus impacting the soil, air and the aqua systems. An oil spill source is identified using models such as positive matrix factorization, geochemical distribution pattern, and spatial distribution pattern [3,4].

Other sources of hydrocarbon pollution in the Niger Delta region of Nigeria include gas flaring, disposal of oil wastes, washings from marine vessels, oil bunkering, runoff from crude oil polluted lands, effluents from refinery, breakage of oil pipelines, well blowout, and maintenance errors [5,6]. The number of crude oil-contaminated sites in Niger Delta region have been reported to exceed 2,000 [7]. Also, overtime, oil spills are said to have produced about 13 million tons of hydrocarbons in the region caused by sabotage, well blowouts, pipeline fatigue, and pipeline vandalism [8, 9]. The contaminated sites are usually at different levels of concentration. In some heavily polluted areas such as the Ogoniland, crude oil concentrations exceed 139,000 mg/kg is reported [10]. These affect land, water sources, and air quality and directly affect the health of local communities, especially where no alternative source of drinking water exists [11]. A high amount of the spilt oil is known to migrate into watercourses such as brooks, streams, and the ocean. Also, a high fraction of the spilt oil mixes with water or sinks into the sediment. Petroleum hydrocarbon pipeline accidents and crude oil leaks due to illegal bunkering impede soil quality and plant growth [12]. This spillage has caused hydrocarbon pollution of both the terrestrial and aquatic environment. Also, both legal and illegal crude oil exploration and or refining lead to the destruction of the fishing industry, thus making fisher folks jobless [13]. This hydrocarbon pollution impedes the survival of the mangroves, marine organisms, and indirectly affect the health, economic and the social status of the communities. However, information on the distribution pattern of the spilt oil in the region is scanty [14]. Thus, its impact on human health, the social lifestyle, and the economy of the region are not adequately reported. The consequence of the effects of the spilt oil on the communities and the environment are enormous. Thus, there is a need to provide the exposure, geochemical and spatial characteristics of the spilt oil in the Niger Delta Region of Nigeria [15].

The characteristics of the aqua environment affected by an oil spill prior to the spillage provide baseline data for understanding the extent of pollution generated by the spillage and involves physical and chemical parameters. The occurrence of the spilt oil draws public attention to the immediate and long-term consequences of the disaster [16]. Investigation of the spilt oil effects in the Niger Delta region of Nigeria overtime is limited to the short-term impact on the environment. The immediate impacts include the destruction of farmlands and fishing points, pollution of watercourses, safety of foods and public health. The long-term impacts include the physical, chemical, and biological processes that lead to a reduction in the nutrient status, biochemical oxygen demand, and chemical oxygen demand of the ecosystem [17]. However, there is limited research on the medium and long-term impacts of the spill to humans. Previous studies have shown that communities in oil spill zones struggle to health, the social, and economic impacts over a medium and a long period [18]. These impacts are never linked with the demographic characteristics of age (*i.e.* adult and non-adult), gender (*i.e.* male and female), literacy (*i.e.* primary, secondary, and tertiary education), and occupation (*i.e.* fish farming, crop farming, public officers and civil retirees). Thus, there is an information gap in how these exposure characteristics affect the response of communities to the oil spill disasters.

In the present study, the authors conducted a multiple sampling using a structured survey questionnaire administered on residents directly or indirectly affected by the oil spill. These activities were aimed at understanding the characteristics of the spilt oil, comprising, sources of the spilt oil, and the risk of direct or/and indirect exposure to the oil spill disaster. The participants in the survey exercise had to recall, the oil spill incident and its impacts on the health, the social, economic, and occupational lifestyle of the people. These activities were followed up with a sampling of water points (*i.e.* Creeks and Brooks) affected by the oil spill. The sampling of water points was aimed at establishing the geochemical database prior to oil spill and the geochemical pattern of the spilt oil. Also, the spatial analysis was conducted to support the outcome of the exposure and geochemical surveys. Concise information on the location and actual status quo of the spilt oil is critical to accomplish an effective treatment of this environmental disaster. Thus, the temporospatial variation study is required to track the oil spill to its source.

Statistical validation was carried out on the survey responses, geochemical distribution pattern, and spatial distribution pattern. Thus, sufficient control of the spilt oil in the Niger Delta region of Nigeria is linked to a comprehensive study and understanding of the linkages of these concepts. These concepts would provide empirical data for stakeholders in decision making.

2 Methods

2.1 Sampling and data analyses

The sampling for assessing oil spill impacts was done in phases. The initial phase was a community random sampling among residents representing different demographic characteristics. The structured questionnaire was administered on residents of oil host communities with coastlines along the Kolo Creek. The total of 900 residents of the targeted impacted region was interviewed. These residents were selected and interviewed based on their ability to recall the oil spill that occurred periodically from 2015 to 2020. The sampling was distributed among the demographic characteristics of age (*i.e.* adult (96%) and non-adult (4%)), gender (*i.e.* male (72%) and female (38%), literacy (*i.e.* educated (83%) and non-educated (17%), and occupation (*i.e.* subsistence farming (45%) and public officers (55%) (Table 1).

Table 1 Demographic characteristics

Age	% (Gender)	% (Literacy)	% (Occupation)	(%)
Adult	96 (Male)	72 (Educated)	83 (Farming)	45
Non-adult	4 (Female)	38 (Non-educated)	17 (Public officials)	55
Total	100	100	100	100

The respondents indicated whether they lived in the coastal communities where the oil spill occurred or if they were indirectly affected by the oil spill. The respondents were grouped into these characteristics such as those exposed to the direct impact and those exposed to the indirect impacts. The questions include "whether the respondent incurred health loss", "whether the respondent incurred any social loss" and "whether the respondent incurred any economic loss of any kind as a result of the spilt oil and the flaring of the spilt oil by the security forces". The respondents were grouped into the nineteen [19] exposure and risk characteristics outlined in Table 2. Also, respondents were asked whether they have justifiable evidence and experience to support their claims. For example, "whether they noticed any colouration and taste of the rainwater and stream water consequent on the oil spill disaster" and whether the sudden changes in the colour of their roofs are associated with the oil spill and flaring of the spilt oil by security forces.

Table 2 Data on exposure characteristics in relation to health, the social and economic impacts

Exposure characteristics	Direct exposure	Indirect exposure	Direct impact			Indirect impact		
			Health	Social	Economic	Health	Social	Economic
Devasted farmland	46.13±2.0	25.45±3.0	45.47	48.47	44.47	25.45	28.45	22.45
Water coloration	87.26±1.52	65.80±3.0	85.60	87.60	87.60	65.80	68.80	62.80
Water taste	86.61±2.0	68.64±3.21	88.95	85.95	84.95	69.98	70.98	64.98
Strained relationships	26.06±1.52	17.31±1.52	25.73	27.73	24.73	15.65	18.65	17.65
Rusty roof	93.96±3.51	75.16±2.51	94.30	97.30	90.30	77.50	75.50	72.50
Smoggy weather	94.65±2.0	81.08±1.52	94.65	92.65	96.65	79.75	80.75	82.75
Reduced income	85.60±3.0	65.16±3.0	86.60	85.60	82.60	68.50	64.50	62.50
Death/injuries	11.02±1.52	7.50±2.0	9.69	10.69	12.69	5.50	7.50	9.50
Relocation	7.34±2.0	6.83±2.0	7.34	9.34	5.34	4.50	7.50	8.50
Yellow foliage	88.06±2.5	76.23±21.62	90.40	88.50	85.30	77.50	76.80	74.40
Crop extinction	65.00±3.1	52.64±2.2	68.51	64.21	62.51	50.41	52.71	54.81
Low crop yield	52.64±2.2	45.86±1.68	62.86	66.56	65.26	47.70	45.50	44.40
Fish extinction	76.92±2.0	66.90±1.63	76.26	75.26	79.26	66.4	68.7	65.5
Dead fish	76.91±2.0	64.73±2.5	74.91	76.91	78.91	62.60	64.50	67.40
Watercourses obstructions	5.95±1.52	5.95±1.52	4.62	5.62	7.62	2.50	3.50	5.50
Reduced recreational activities	7.34±1.0	3.40±1.0	6.34	8.34	7.34	4.40	3.40	2.40
Property loss	8.02±2.08	5.78±1.52	8.69	9.69	5.69	7.45	4.45	5.45
Lost jobs	34.43±1.73	24.5±1.0	35.43	32.43	36.43	25.50	23.50	24.50
Diet and eating	24.73±2.0	14.16±1.52	22.73	24.73	26.73	12.50	15.50	14.50

2.2 Data analyses

Consequent on sampling, a descriptive summary of demographic characteristics, exposure characteristics in relation to health, the social, and economic impacts have been reported (Table 1 and Table 2). Subsequently, multiple correlation data was run with SPSS to validate correlations between exposure characteristics of health, the social and economic impacts. These characteristics were correlated based on the direct and indirect impact of the spilt oil. In each case of exposure characteristics, the means and standard deviations of these impacts were reported (Table 3).

2.3 Exposure distribution pattern

An inclusive exposure assessment included a broad range of exposure events across the lifespan of the respondents. Due to inadequate space in a large, multifaceted survey, reporting is centred on grouping the respondents and categorizing the same into nineteen exposure characteristics. The exposure characteristics that have strong demographic properties that are

Table 3 Multiple correlations of exposure characteristics to health, the social and economic impacts of the spilt oil

		Correlations					
		Direct impact			Indirect impact		
		Health	Social	Economic	Health	Social	Economic
Health Direct impact	Pearson Correlation	1	0.998**	0.996**	0.982**	0.987**	0.983**
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
	Covariance	1229.574	1206.779	1196.053	1087.161	1062.556	987.505
	N	19	19	19	19	19	19
SocialDirect impact	Pearson Correlation	0.998**	1	0.995**	0.982**	0.985**	0.977**
	Sig. (2-tailed)	0.000		0.000	0.000	0.000	0.000
	Covariance	1206.779	1189.585	1175.769	1069.047	1043.278	965.455
	N	19	19	19	19	19	19
Economic Direct impact	Pearson Correlation	0.996**	0.995**	1	0.977**	0.984**	0.984**
	Sig. (2-tailed)	0.000	0.000		0.000	0.000	0.000
Covariance	1196.053	1175.769	1173.565	1056.110	1034.301	965.317	
	N	19	19	19	19	19	19
Health Indirect impact	Pearson Correlation	0.982**	0.982**	0.977**	1	0.976**	0.981**
	Sig. (2-tailed)	0.000	0.000	0.000		0.000	0.000
	Covariance	1087.161	1069.047	1056.110	996.164	945.323	886.643
	N	19	19	19	19	19	19
Social indirect impact	Pearson Correlation	0.987**	0.985**	0.984**	0.976**	1	0.983**
	Sig. (2-tailed	0.000	0.000	0.000	0.000		0.000
	Covariance	1062.556	1043.278	1034.301	945.323	942.397	864.979
	N	19	19	19	19	19	19
Economic indirect impact	Pearson Correlation	0.983**	0.977**	0.984**	0.981**	0.983**	1
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	
	Covariance	987.505	965.455	965.317	886.643	864.979	820.827
	N	19	19	19	19	19	19

Notes: **. Correlation is significant at the 0.01 level (2-tailed).

statistically valid were selected to enhance statistical testing, retesting and constructive validity (Table 3). The respondents indicated if the oil spill has a relationship with devasted farmland, water colouration, water taste, strained relationships, rusty roof, smoggy weather, reduced income, death/injuries, relocation, yellow foliage of plants, crop extinction, low crop yield, fish extinction, dead fish, obstruction to watercourses, reduced recreational activities, property loss, lost jobs, diet, and eating pattern.

2.4 Geochemical distribution pattern

Geochemical sampling started at Ebelebiri environ at the upstream section of the Kolo Creek where there was visible evidence of the spilt oil from an exploration pipeline. This sampling was centred on the aqua system and sediment within the Kolo Creek that visibly contained the oil spill. This activity continued down-streaming to the last community within the Kala Kolo environ of the Creek. Water samples below the surface were collected using a glass Winchester bottle that was handline operated (Figure 1).

The parameters analyzed from the oil spill contaminated water included pH, salinity (Sal), turbidity (Turb), total dissolved solids (TDS), total suspended solids (TSS), nitrate (NO_3), chloride (Cl), sulphate (SO_4), bicarbonate (HCO_3), total alkalinity (TA), Total hardness (TA), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), manganese (Mn), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total hydrocarbon (water THC), and total petroleum hydrocarbon (water TPH).

The oil spill-contaminated water was sampled in triplicate and transported to the laboratory for analyses. These samples were analyzed for physical characteristics, chemical characteristics, COD, BOD, water THC, and water TPH. The analytical procedure followed the American Public Health Association [19].

The chemicals and reagents used in the analyses were of analytical grade, supplied by Sigma Aldrich in Dorset, United Kingdom. These materials were used to create the required standard solutions. The water samples were analyzed for pH using a portable Orion Model 290 pH meter obtained from the Leicester United Kingdom; salinity using Mohr's method; turbidity using the HACH turbidimeter obtained from Manchester, United Kingdom; TDS and TSS using a HACH-TSS-TDS meter obtained from Manchester, United Kingdom; conductivity using an Oakton Model 35607 conductivity meter obtained from Leicester, United Kingdom; anions using a Compact high- performance ion chromatography, 761 Compact IC fitted with the 813 Compact IC autosampler system supplied by Metrohm, Switzerland, (P.N. 6.2620.110), and THC using

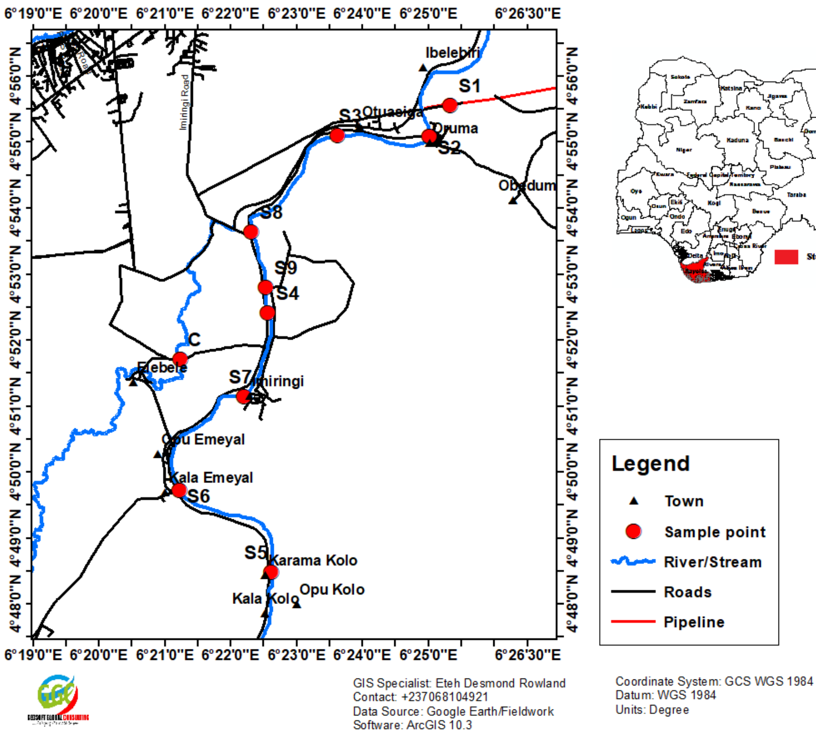

Figure 1 Sample locations in the study area

the titrimetric method. A Perklin Elmer atomic absorption spectroscopy (Perkin Elmer AAS PinAAcle 900Z with furnace autosampler AS900) obtained from Spectralab (Ontario, Canada) was used to analyze the major cations. Some titrimetric and colourimetric procedures were used to determine the COD and BOD respectively [11].

The measurement of organic pollution applicable to both wastewater and surface water is the biochemical oxygen demand (BOD_5) measured for a 5-day period [20]. This parameter represents the amount of oxygen (mg/L) that bacteria utilize from water during the oxidation of organic matter. The dilution method of the American Public Health Association (APHA) was used in this study [19].

A measure of the chemical oxygen demand (COD) provides the oxygen equivalent of the organic matter content in a sample prone to oxidation using a strong oxidant. The dichromate reflux method was used in this investigation [21].

To determine both the total hydrocarbon content and total petroleum hydrocarbon in water and sediment, water samples were collected at a depth of 5 cm below the water surface, using a glass Winchester bottle that was handline operated. The water samples were filtered preserved with 1M hydrochloric acid (HCl), and subsequently stored in amber bottles at 4°C for use within 14 days of collection. Sediment samples were collected along the bed of the watercourses. A 30.0 mL toluene solvent was used in the extraction process for the water samples. A liquid-liquid extraction procedure was conducted on the sediment samples using 30 mL dichloromethane (DCM) as the extracting agent. A control sample was obtained off the oil spill coastline. The content was securely sealed with a stopper and subsequently agitated for 20 minutes. The organic layer clearly separated from the aqueous phase was collected. The extraction procedure was repeated thrice and the content made up to 100 mL. The blanks and absorbances of the filtrates were determined by runs with UV fluorescence spectroscopy (UVF) on a Hitachi F-2000 Fluorescence spectrophotometer from the United Kingdom. A 310 nm excitation and 374 nm emission wavelengths were used to determine the fluorescence of the samples. The concentration of the total hydrocarbon content and the total petroleum hydrocarbon were determined from the calibration graph respectively [22].

2.5 Spatial distribution pattern

The data were collected using a handheld global positioning system (GPS) in degree, minute, second and imported into Microsoft Excel where the data was converted to degrees in decimal. Oil spill mapping included the incorporation of the geographical, remote sensing and oil pipeline data detected by satellite imagery. The data analysis for the spatial pattern of the spilt oil in the study area was done using Arc GIS 10.6. A spatial analyst extension was applied. Subsequently, the converted data were transferred to a geographical information system environment in a database. That format was used to generate a study area map. Also, the spatial interpolation method was used to generate some spatial distribution maps (*i.e.* pollution maps) using inverse distant weight (IDW) techniques. Besides, SPSS software was used for statistical analysis of the data [23]. The procedures were replicated three times and the results reported as mean ± standard deviation. Pearson correlation coefficient and principal component analysis were used to do statistical validation. The correlation was done using a two-tailed test at $P < 0.01$

3 Results

3.1 Demographic characteristics and sample description

Demographic data include age, gender, literacy, and occupation as covariates in the analyses is reported (Table 1). The sample is of majority adult, majority male, majority educated and roughly half farmers and public servants.

3.2 Exposure distribution pattern

The responses to exposure characteristics are provided in Table 2. These responses varied across respondents with direct and indirect exposures and across health, the social, and economic dimensions. The respondents affected by direct exposure to the impacts were high when compared to respondents with indirect exposure. The respondents who were directly impacted by the oil spill were most concerned about the smoggy weather, closely followed by the rusty roofs, used for rainwater harvesting by the residents in the communities. The oil spill affected the only source of potable water in the region. However, the respondents were least concerned about the reduced recreational activities in the region. That means, the smoggy weather did not affect outdoor activities in the study area. Consequent on the correlation triangles generated in Table 3, there is a high degree of correlation between the direct exposure of respondents to health impact versus direct exposure of respondents to the social impact and economic impact. These impacts are statistically significant at $p < 0.01$. Also, the correlation between direct exposure of respondents to health impact versus indirect exposure to the social and economic impacts are significant at $p < 0.01$. The correlation between the direct exposure of respondents to the social impact and health and economic impacts, be they direct or indirect are significant at $p < 0.01$.

3.3 Geochemical distribution pattern

The physical and chemical characteristics of the spiltoil-contaminated water are presented (Table 4). However, only the most widely used parameters that affect the degradation of the hydrocarbon (*i.e.* BOD and COD) are considered along with the total hydrocarbon content and total petroleum hydrocarbon. The comparison of BOD with COD provides information on whether the organic matter is readily biodegradable. For example, a COD: BOD ratio of greater than 100 is an indication that the organic matter is non-biodegradable. Besides, a ratio of less than 10 is an indication that it is degradable [20]. The descriptive statistics showing the mean, standard deviation, variance, skewness, and kurtosis in ascending order are presented (Table 5a). The correlation coefficient between hydrocarbon parameters of BOD, COD, water THC, and water TPH are provided (Table 5b). All parameters have high correlation values and are statistically significant at $p < 0.01$.

The extraction method was used to perform principal component analysis (PCA) (Table 5c and Table 5d). Cumulative % of component explains the values of the total variance in variables which are included on the component. The result for PCA indicates four main controlling factors underlying the geochemical distribution pattern namely BOD, COD, water and sediment THC and TPH. The communalities for all of the variables included on the components were greater than 0.5 and had simple structures. 99.14% of the total variance obtained from the component analysis suggests a strong loading of BOD, COD, water THC, and water TPH. These parameters are strongly correlated and suggested a common source [24].

The sediment samples recorded higher values of both THC and TPH when compared with the water samples. The highest concentration was observed at site S1, followed by S2, down to S9 at the downstream section of the study area. S1 is a site at the vicinity of a broken pipeline conveying crude oil out of a flow station to a depot.

Also, site S1 is a part of an oil spill site at the upstream section of the sampled Kolo Creek that supplies hydrocarbon pollution downstream. This high level of hydrocarbon pollution may be unconnected to anthropogenic activities. There are no commercial activities such as fishing with speed boat, thus, the discharge of engine oil or lubricating oil into the water by the engine of the fishing boat does not arise [25]. Generally, the water THC and water TPH concentrations are lower at the control site compared to the concentrations in the study area.

Table 4 Physical and chemical characteristics of the spilt oil-contaminated water with * as control

Sample Code	pH	Salinity	Cond	Turbidity	Total Dissolved Solids	Total Suspended Solids	Total Alkalinity	Total Hardness	BOD	COD	water THC	water TPH	sediment THC*	sediment TPH*
Units		μs/cm	μs/cm	NTU	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	6.30	9.9	35,000	25.50	15.50	11.25	12.5	32.50	22.15	40.5	32.16	121.26	37.50	126.40
2	6.51	0.02	56.3	22.62	1.03	3.03	10.50	28.50	20.50	38.50	30.50	120.50	34.55	124.45
3	6.45	0.02	52.80	20.05	6.85	2.85	11.60	25.40	18.45	30.80	28.40	110.40	32.50	113.60
4	6.40	0.05 5	0.40	18.45	13.70	2.75	12.80	23.50	15.80	20.75	20.70	78.60	24.50	86.50
5	6.35	0.03	49.50	16.50	17.40	2.50	13.90	22.60	11.60	13.60	13.40	50.75	18.55	56.70
6	6.60	0.04	48.60	15.30	21.50	2.45	14.80	21.70	5.50	7.50	6.50	24.00	12.45	39.50
7*	6.65	0.02	45.50	14.86	23.00	2.35	15.00	18.00	2.18	2.35	0.28	0.18	1.50	1.20
8	6.40	0.03	49.10	15.42	25.30	2.42	16.00	20.00	3.48	5.13	1.68	2.48	3.50	4.55
9	6.42	0.03	50.90	14.76	26.40	1.30	13.00	15.00	4.50	6.69	2.47	3.73	3.25	3.80
10	6.62	0.03	49.40	13.85	25.00	1.38	14.00	19.00	3.92	5.61	2.55	2.68	2.90	3.10

Table 5a: Descriptive Statistics for hydrocarbon parameters in surface water

	N	Min.	Max.	Mean	SD	Variance	Skewness (SE)	Kurtosis (SE)
BOD	10	2.18	22.15	10.80	7.81	61.12	0.34 (0.68)	-1.80 (1.30)
COD	10	2.35	40.50	17.14	14.57	212.46	0.74 (0.68)	-1.20 (1.30)
Water THC	10	0.28	32.16	14.10	12.74	162.39	0.42 (0.68)	-1.79 (1.33)
Water TPH	10	0.18	121.26	51.24	52.17	2722.45	0.38 (0.68)	-1.85 (1.33)

Table 5b: Pearson CC between hydrocarbon parameters in surface water samples

	BOD	COD	Water THC	Water TPH
BOD	1.000			
COD	0.979**	1.000		
Water THC		0.996**	0.986**	1.000
Water TPH	0.993**	0.980**	0.998**	1.000

Notes: CC: correlation coefficients; ** significant at the 0.01 level (2-tailed).

Table 5c: Factor loadings of PCA showing total Variance explained for hydrocarbon parameters in surface water samples

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.966	99.14	99.14	3.96	99.14	99.14
2	0.026	0.64	99.79			
3	0.007	0.18	99.97			
4	0.001	0.027	100.00			

Table 5d: Component Matrix

	Component
BOD	0.996
COD	0.990
Water THC	0.999
Water TPH	0.997

3.4 Spatial distribution pattern

The spatial distribution pattern of the spiltoil-contaminated area is provided as icicle diagram (Figure 2), dendrogram (Figure 3), pollution map for BOD (Figure 4a), pollution map for COD (Figure 4b), pollution map for water THC (Figure 4c), and pollution map for TPH (Figure 4d). Also, graphs of BOD versus sample location (Figure 5a), COD versus sample location (Figure 5b), water THC versus sample location (Figure 5c), and water TPH versus sample location

(Figure 5d) are presented. In all these presentations, there is a gradual and systematic decline in the volume of hydrocarbon downstream of the sampling points.

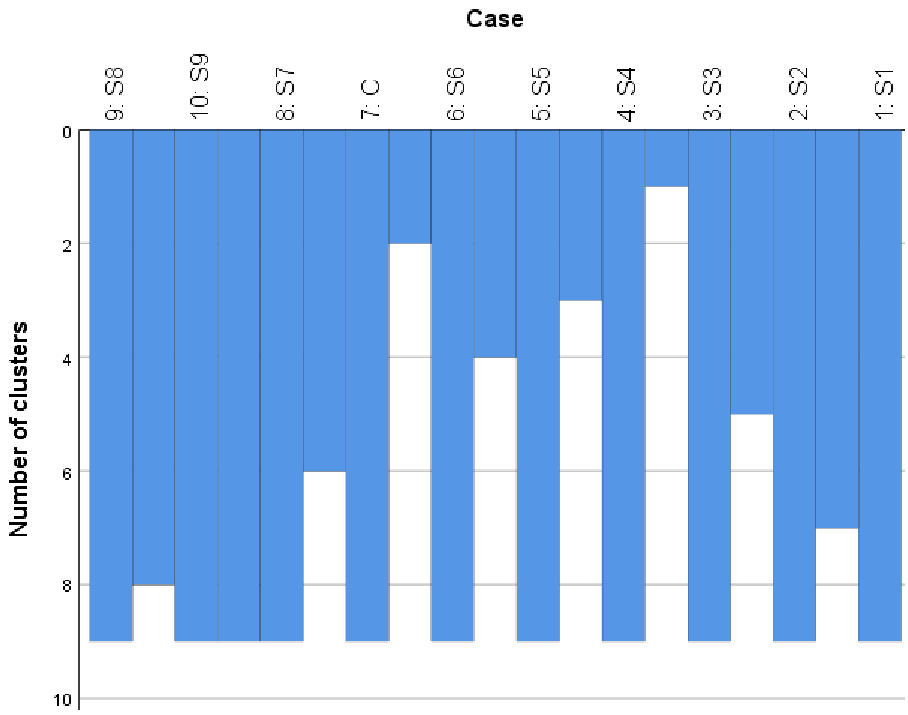

Figure 2 Icicle diagram for hydrocarbon parameters in surface water sample in the study area

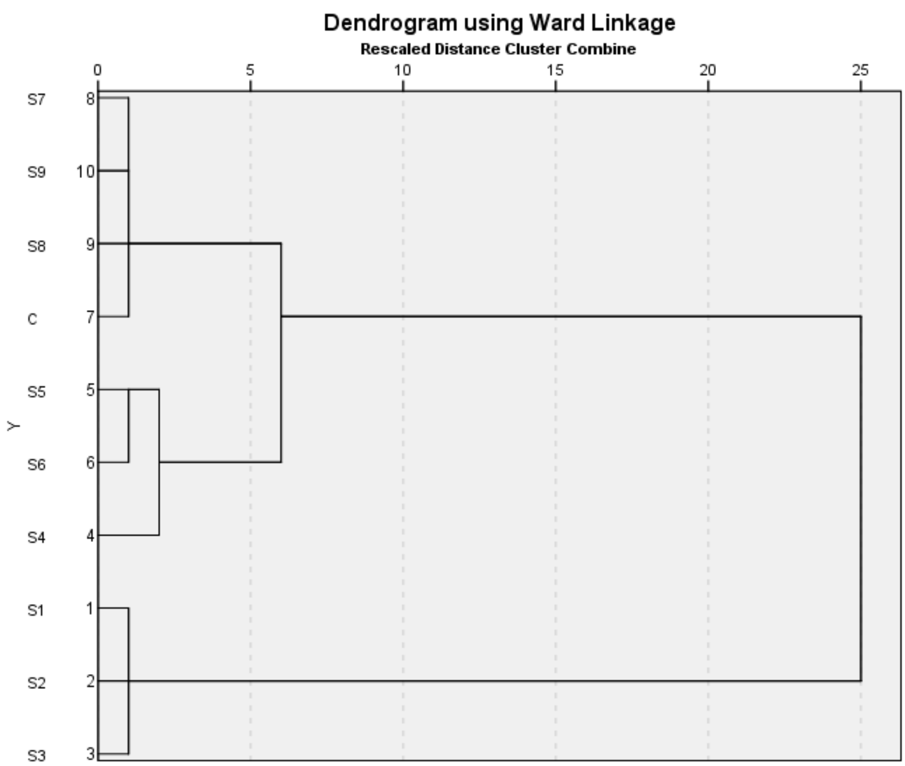

Figure 3 Dendrogram of sampling locations in terms of hydrocarbon parameters in surface water

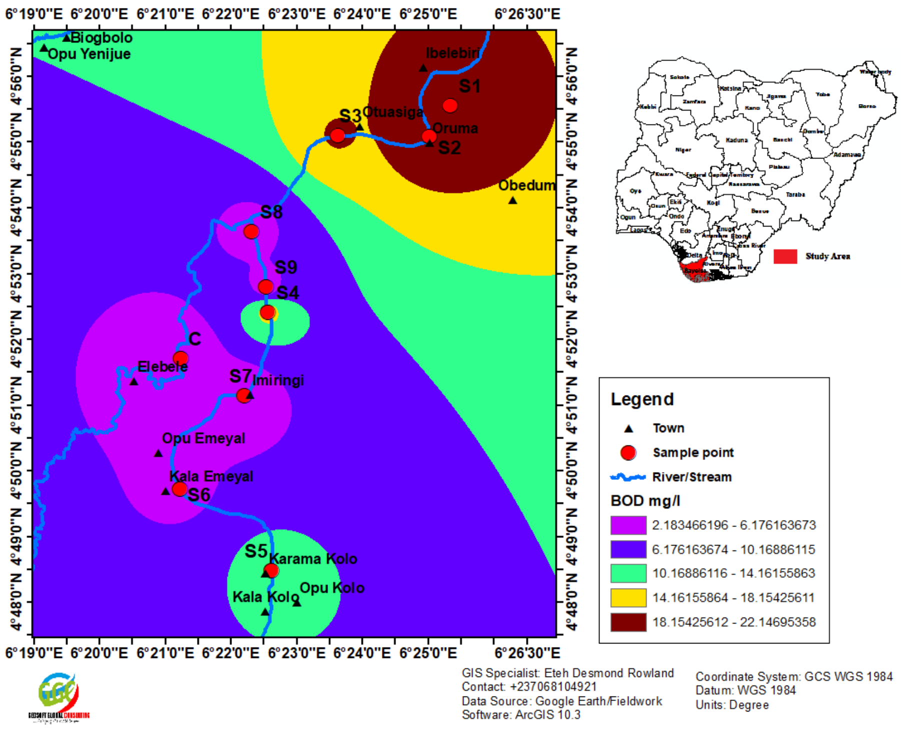

Figure 4a: Spatial distribution pollution map for BOD

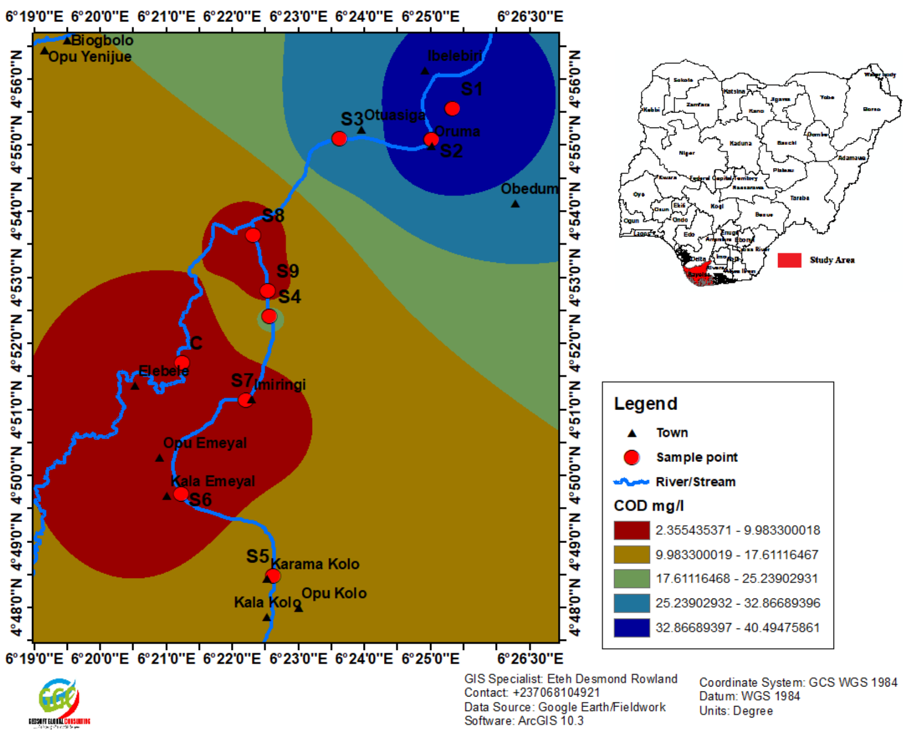

Figure 4b: Spatial distribution pollution map for COD

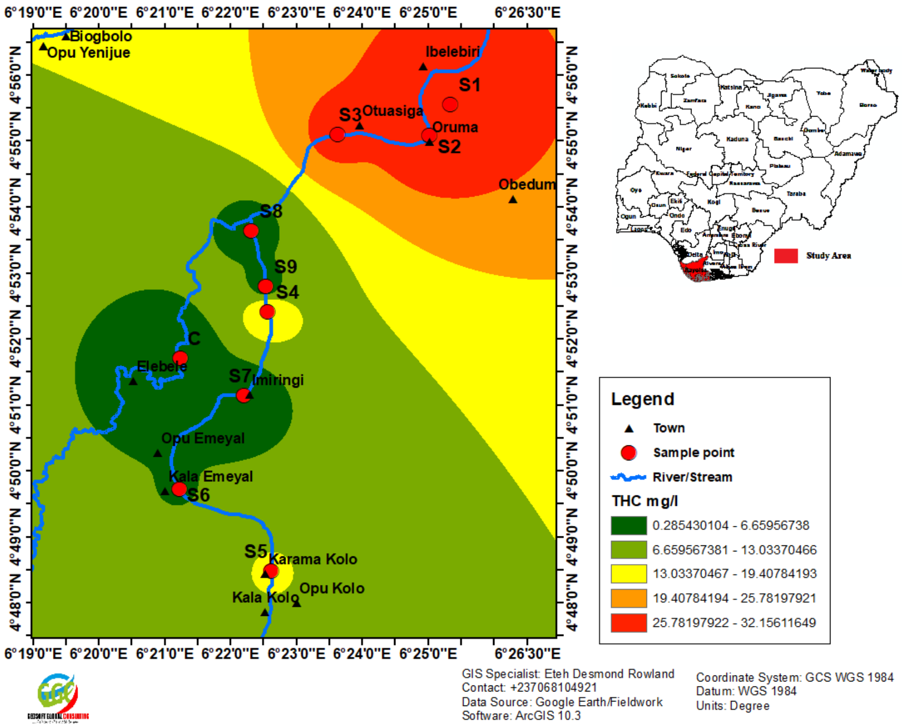

Figure 4c: Spatial distribution pollution map for water THC

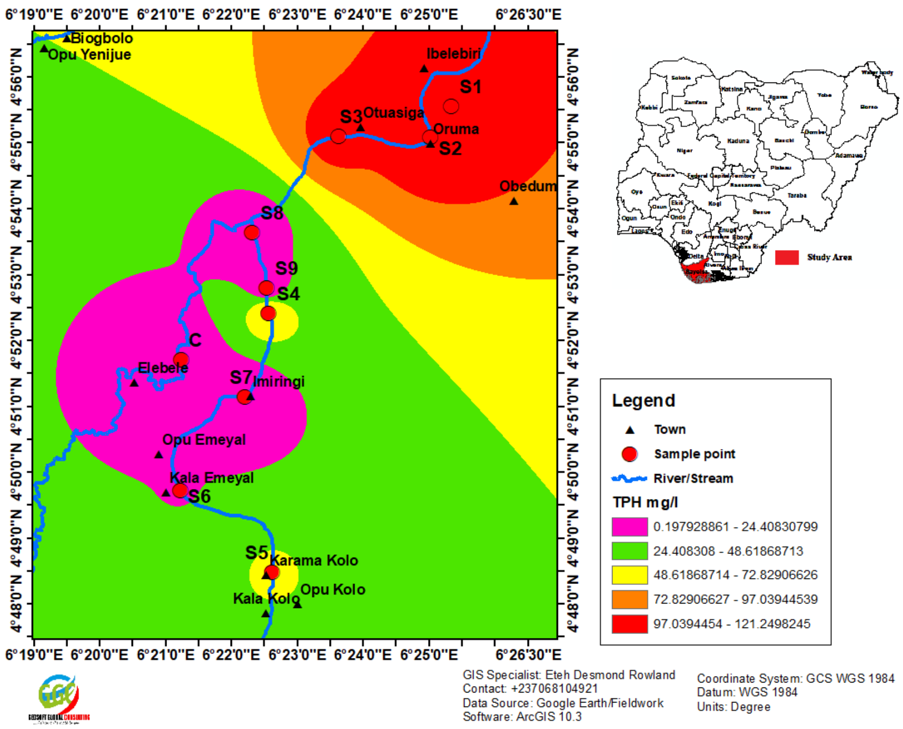

Figure 4d: Spatial distribution pollution map for water THP

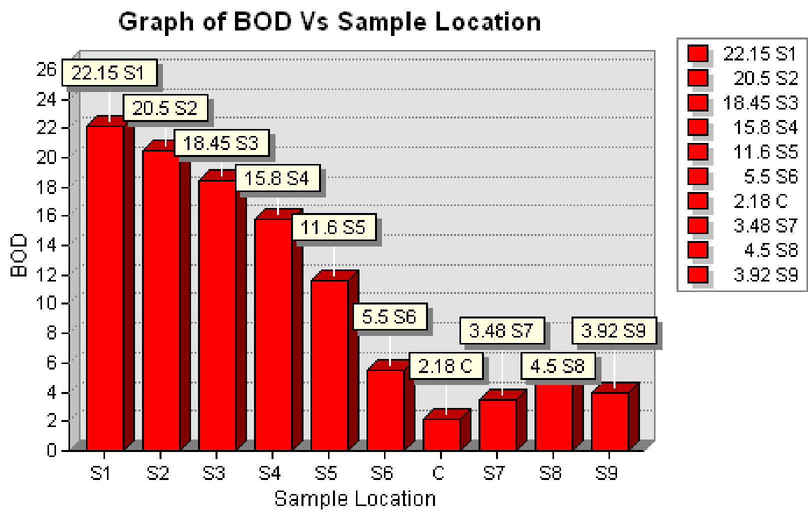

Figure 5a: Graph of BOD versus sample location

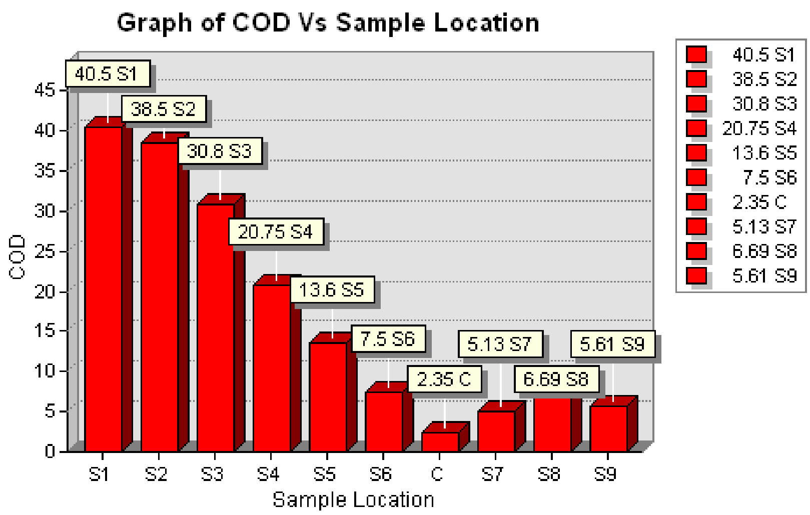

Figure 5b: Graph of COD versus sample location

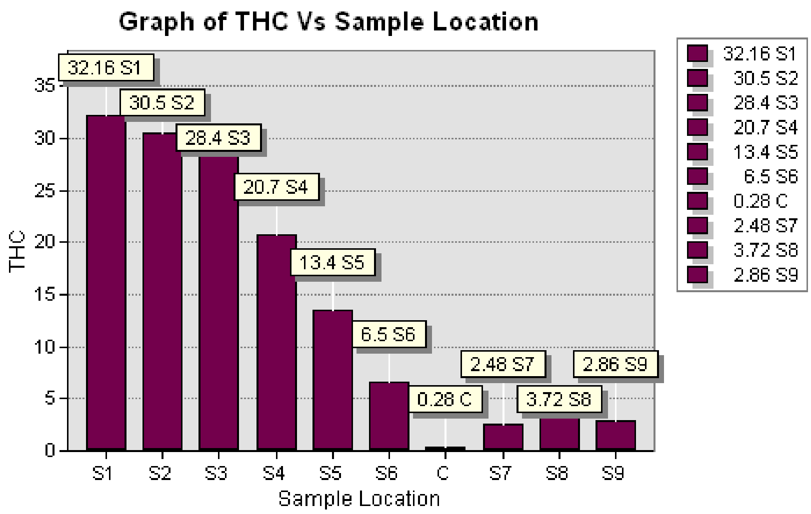

Figure 5c: Graph of water THC versus sample location

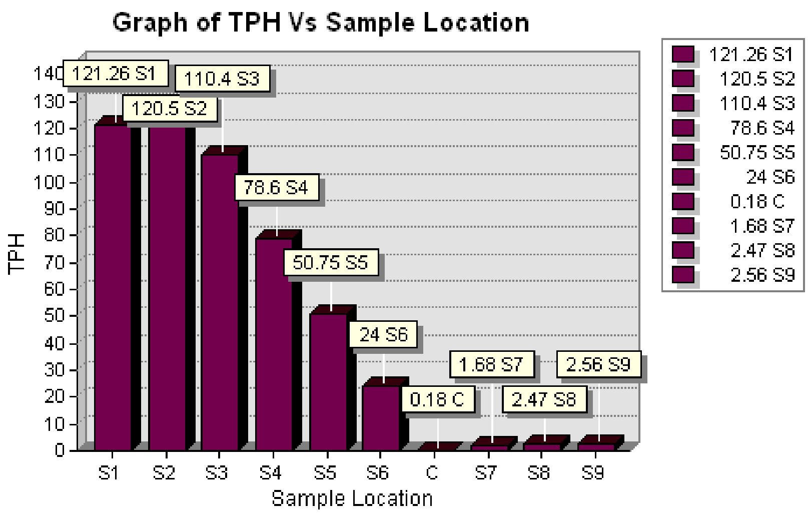

Figure 5d: Graph of water TPH versus sample location

4 Discussion

4.1 Exposure distribution pattern

In this study, we examined the exposure, geochemical and spatial distribution patterns of an oil spill along the coastlines of the Kolo Creek in the Niger Delta region of Nigeria. The exposure pattern was characterized using socio-demographic characteristics in relation to health, the social and economic impacts on the residents along with the coastal communities [26]. There is statistical evidence that in spite of the establishment and operation of NOSDRA, oil spill in this part of the Niger Delta region impacted on the exposure characteristics used in the study. Most respondents, whether directly or indirectly affected by the spilt oil are of the view that higher exposure to health impact correlates with higher exposure to the social and economic impacts. Since the spilt oil affected the only source of potable water in the region, the health effect translates into the social and economic issues [26]. The stream water in this region provides the source of livelihood for fisher folks. The frequent eruption of burn-fire in spilt oil sites generates smoggy weather, closely followed by the rusty roofs in these communities. These characteristics demonstrate that the singular effect of the spilt oil on watercourses produces a spiral effect on the health, the social, and economic activities of residents in the spilt oil communities.

4.2 Geochemical distribution pattern

The observed values of both BOD and COD indicate that the organic matter inclusive the hydrocarbon is readily biodegradable. The mean concentration of water and sediment THC and TPH from all sample sites are higher than the European Union Environmental Protection Agency limits of 300 μ/gL for petroleum hydrocarbons in surface water and basin structures [28]. This comparison brings to the fore that oil spill pollution enhances the mortality risk in fence-line communities. Thus, the results are consistent with previous studies in this region and meet global perspective [29]. High levels of water THC and TPH were reported for both surface water and groundwater samples (1352-12,110 μg/L and 73,500 μg/L, respectively) in some communities in Niger Delta region of Nigeria [30]. The water and sediment THC and TPH in the present study are lower than the mean value of water and sediment THC and TPH in the coastal terrain of South Eastern Nigeria [30]. Also, the high values of THC and TPH for the sediments compared to the water THC and TPH is attributed to the fact that samples investigated were collected long after the oil spill incidence occurred. Also, this characteristic indicates that the heavier fractions of petroleum hydrocarbon migrates through the water column and settle at the bottom of the stream. However, some hydrocarbon fractions mix with water and penetrate to the underlying sediment. Besides, the lighter hydrocarbon fraction evaporates easily during high temperature and high wind. The concentration of water and sediment THC and TPH in the study area are lower than values recorded in the Sombreiro River, another seriously impacted area reported by [31]. This oil spill site hosts flow-stations, wellheads and several pipelines that convey petroleum products. Thus, the level of water and sediment THC and TPH are reported higher in coastal areas than the open sea [32]. This difference is due to seasonal fluctuations, thus resulting in dilution, mixing, and dispersion of the pollutants.

The sediment THC and TPH recorded in this investigation may account for the extinction of mangrove vegetation in the study area, and is in agreement with the record of, that the oil spill has a deleterious effect on the sub-tidal and intertidal vegetation. Consequently, organisms such as periwinkles and mudskipper that are vulnerable to oil pollution are in extinction [33]. The high level of water and sediment THC and TPH above recommended limits in the environment accounts for the extinction of certain fish species and the observed dead fishes in the study area. High THC and TPH are ingested by microbiomes, planktons, crustaceans, crabs, periwinkles, and fish [33]. This ingested hydrocarbon is passed along the food chain. This process supports the view of respondents that the oil spill in the study area negatively impacts on the health, the social, and economic lifestyle of the communities. Thus, there is a need for the NOSDRA to review its performance and be proactive in enhanced detection and response to spilt oil in the Niger Delta region of Nigeria. This proactiveness will save the aquatic environment, sustains potable water, and ensure excellent quality of human health, the social, and economic emancipation of the Niger Delta region.

4.3 Spatial distribution pattern

Geographic information systems (GIS) contribute to the reliable interpretation of the spilt oil signatures in the study area. Thus, GIS provides information for oil spill prediction, offshore/onshore sources, oil pollution weighting, identification, and classification of the spilt oil, shown as oil spill distribution maps in the study area. The spatial distribution pattern agrees with the concepts and results of the exposure distribution pattern and the geochemical distribution pattern. The spatial distribution pattern displays the areal extent of the spilt oil based on oil spill weighting. The pollution maps are useful for spill planning and response since they sustain integration of the geospatial information on the location, and nature of the spilt oil [34]. NOSDRA is better equipped by these pollution maps to develop a geospatial technology for oil spill management.

5 Conclusion

In this study, there are clear pieces of evidence that there exists a strong correlation between exposure distribution pattern, geochemical distribution, and spatial distribution of the spilt oil reported along the coastlines of the Kolo Creek in the Niger Delta region of Nigeria. Respondents directly affected by the oil spill reported that the smoggy weather condition is closely linked to the rusty roofs observed in the communities. Thus, the rainwater harvested in the oil spill communities possesses dark coloration and is highly contaminated. There exists a spiral effect of the spilt oil to the health, the social, and economic lifestyle of the residents.

Also, the observed values of both water and sediment THC and TPH in the present study is highest at site 1 (S1), decreasing downstream. Also, the mean concentration of water and sediment THC and TPH from all sample sites are higher than the European Union (EU, 2020) limits of 300 μg/L for petroleum hydrocarbons in a surface water and basin structures. The differences in THC and THP in this study area and other parts of the Niger Delta region indicate periodic sampling is necessary to achieve accurate data on the level of hydrocarbon pollution in the region. The BOD and COD values indicate the readiness of the hydrocarbon for natural bio-degradation and ingestion by planktons, crustaceans, crabs, periwinkles, and fish. The presence of dead fish at the oil spill site supports the view of respondents that, the oil spill negatively impacts significantly the health, the social and economic lifestyle of the communities.

Besides, the spatial distribution pattern supports the concepts and results exposure and geochemical distribution pattern. The oil spill weighting provided by the pollution maps supports that the oil spill site is sourced from a pipeline located at site 1(S1). This study provides NOSDRA, with pollution maps and geochemical indices to develop a geospatial technology for oil spill management. However, further work is required on the mitigation measures for this oil spill and the use of biosurfactants to treat the oil spill sites.

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