Natural Implications of Crude Oil Spillage: A Case Study of Otuokpoti Oil Field, Bayelsa, Nigeria

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Abstract

This study determined the ionizing radiation concentration and heavy metal concentrations of water and soil specimen collected from Otuokpoti oil field, Nigeria, whose area is unfortunately prone to contamination from oil facilities installed in the region. A reconnaissance investigation was first carried out using the remote sensing technique (Data: Landsat 7) where Land/vegetation, urban and water bodies were classified, and relationships were illustrated using a scatter plot of their spectra bands. The Normalized Difference Vegetation Index (NDVI) and the Soil Adjust Vegetation Index (SAVI) were used to access the vegetation health.

The results show that the mangrove vegetation is relatively unhealthy as shown in both NDVI & SAVI, respectively. Further analysis to assess soil and water quality in the area was carried out. Samples were analysed for radiation level, pH, and heavy metal concentration using Radiation Alert Inspector, Atomic Absorption Spectrophotometer (AAS), and pH meter. A mean pH of 8.64 and 6.4 was obtained for the soil and water samples, respectively. A substantial number of heavy metals such as Lead (Pb), Zinc (Zn), and Iron (Fe) were also recorded in the soil samples which was above the World Health Organisation (WHO) recommended level for drinking and domestic water.

Keywords
Concentration, Heavy Metal, NDVI & SDVI, Radiation, and Spillage.

1. Introduction
Environmental quality can be influenced by industrial corporations' activities such as oil and gas facilities, chemical processing facilities, Wyrick et al (2012). These activities result in pollution associated with petroleum products, which is a significant source of concern for sustainable development and impacts on inhabitants' living conditions in affected areas, Nath et al. (2016). In Nigeria, The Niger Delta happens to be one of the regions with unfavourable living conditions for residents despite its rich oil and gas resources. It has been recorded that Nigeria depends majorly on the proceeds from the sales of energy products in the Niger delta. The continuous exploration & exploitation of oil and gas both by International Oil Companies (IOCs) and illegal bunkering without proper environmental impact assessment has left the Niger Delta in a sorry state limiting residence with access to drinkable water fertile lands for farming due to oil spillage which is a frequent consequence of oil exploration and exploitation with an estimated total of over 7000 oil spill accidents reported over 50 years. Natural gas combustion and oil spillage have adverse radiological effects, results in variation in pH level and release of toxic heavy metals in the environment, Chadwick (2019).

Previous studies record that crude oil was first found in marketable quantity in 1956. From that point forward, the district has persistently endured the adverse natural effects of oil-gas exploration Ite et al. (2013). Chinedu and Chukwuemeka (2018) reviewed the oil spillage incidence from 1976 to 2014 based on both government and non-governmental agencies' data (figure 1). The result shows that residents in the Niger Delta region may be at risk of heavy metal toxicity due to the continuous exposure to a high rate of a crude oil spill of about 3.1 million barrels. In February 1995, a pipeline oil spillage at Ogada-Brass of almost 24,000 barrels of oil affected the freshwater swamp forest and into the mangrove swamp. Similarly, since 1989 the Shell Petroleum Development Company (SPDC) recorded a regular spill of 221 every year in its operational terrain, including 7,350 barrels yearly Kadafa (2012).

Therefore, this study investigates the impact of the oil spill in a section of Otuokpoti community by accessing the heavy metal concentration on the environs through preliminary and reconnaissance investigation, sample collection, preparations, design, and analysis for pH values estimation of water and soil samples followed by the identification of radioactive concentration of heavy metal and its variation in the terrestrial and aquatic regions.

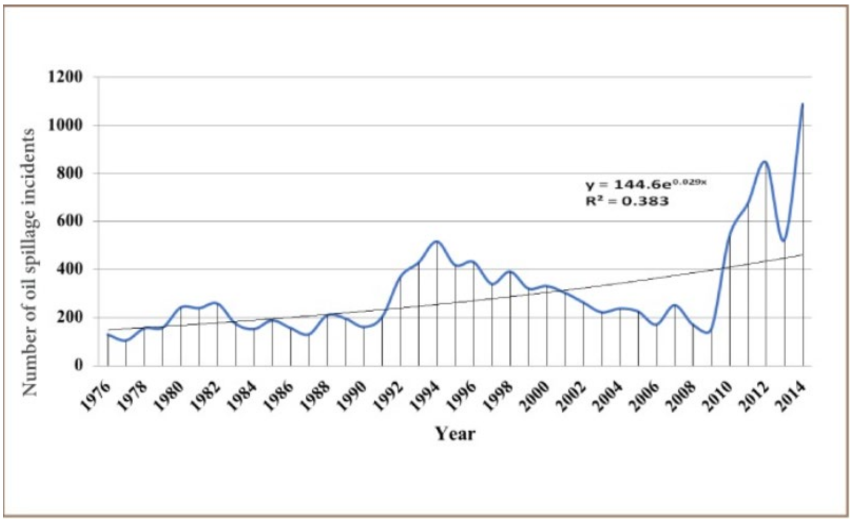


Figure 1. Trends of oil spillage in Nigeria from 1976 to 2014 (Chinedu & Chukwuemeka, 2018)

2. Literature Review

Radioactivity is a property of most minerals, and its level is dependent on the concentration and type of the radioactive component (isotope) in the mineral Kovler (2017). Naturally occurring radionuclides (NORN) are significant sources of ionizing radiation in the environment and occur in three forms: Alpha, Beta, and Gama radioactivity Goronovski et al. (2018). NORN present in soil and water usually depends on an area's geological attribute and anthropological activity. The concern in crude oil exploration is associated with the fact that radioactive elements are present in petroleum and petroleum-related products Coppock and Christian (2018). Hence, these activities have been reported to increase the level of radioactivity in an active site. As an illustration, Adewumi (2016), examined the effect of the oil-gas industry on the characteristic radioactivity dissemination in the Niger Delta area. They reported that the average action fixation for 40_K , 238_U and 234_{Th} radionuclide are 34.8 ± 2.4, 16.2 ± 3.7 and 24.4 ± 4.7 $Bq\ Kg^{-1}$ respectively for zones having exploration activities. These zones were observed to have more radioactivity than zones with no exploration activities.

Also, crude oil exploration with resultant spillage releases some heavy metals such as Lead, arsenic, chromium, mercury, cadmium and thallium into surrounding soil and water Peter et al. (2020). In soil, heavy metal contamination has been demonstrated to increase toxicity, lead to soil degradation and loss of fertility, reduce agricultural productivity, bioaccumulation and death in plants, and contaminate groundwater sources used for domestic and irrigation purposes Adewumi (2016). Similarly, heavy metals in water could result in bioaccumulation in humans and aquatic organisms with consequential health impact Carolin et al. (2017). Heavy metals also impact the usability of water for various essential uses. Okiongbo and Douglas (2015) used multivariate statistical methods to evaluate the principal reasons influencing groundwater geochemistry in Yenagoa. The result reveals that groundwater's hydrogeochemical properties in the area are slightly acidic and below the prescribed WHO limit for drinking water.

Similarly, Olu et al. (2019) did a Laboratory, and statistical analysis of samples collected from the Soku Oil field area reports a very high concentration of heavy metal during the dry season and possess a high dilution during the wet season. Although the results from Oribhabor and Ogbeibu (2014) assessment of heavy metals in the Buguma creek shows that surface water was not polluted as the hydrocarbon contents were less than 1mg/l. However, Ojo and Makinde (2019) gave a contrary report that some metals were observed in seafood samples but with lower compositions when compared to those in Ekerekana.

Therefore, heavy metal contamination of soils and water in crude oil-contaminated areas has been regarded as a significant cause for environmental concern Mao et al. (2018) as there are increasing occurrences of oil spillage per year as shown in figure 1.

3. Methods

A preliminary & reconnaissance investigation was carried out in Yenagoa local government areas using satellite imagery (Landsat 7). The maximum likelihood classification of Land/vegetation, River, and Settlement was performed using 26 training samples collectively. A scatter plot of urban areas and water was created to see the correlation between each spectra band. The Normalize Difference Vegetation Index (NDVI) and the Soil Adjusted Vegetation Index (SDVI) were carried out to identify the health condition of plants in the environment. Furthermore, surface water and strata at both river banks and on the land of affected areas were collected and analyzed in the laboratory using the atomic absorption spectrophotometer (AAS). The results were tabulated, analyzed statistically, and visualized graphically.

3.1. Description of the Study Area

The area of concern in this study is located at Otuokpoti town in Bayelsa State, Nigeria and lies within latitude 4°23.3 and 4°38.2 North and longitude 6°30 and 6°40 East and is situated in the eastern part of Bayelsa State. It is accessible by both road and riverine routes.

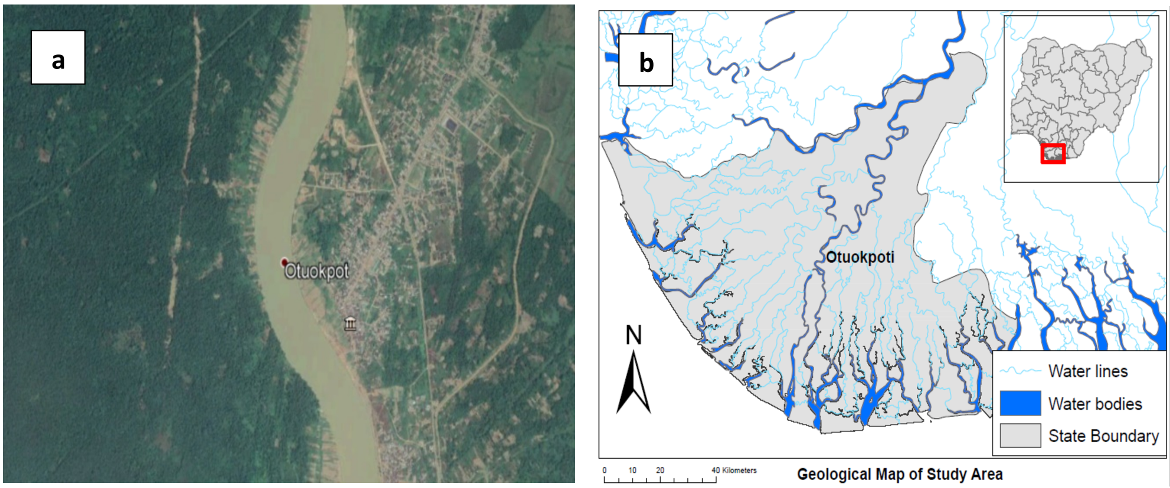


Figure 2. (a) Location of the study area (Source: google earth pro), (b) Thematic map of study area.

This region is located within the lower delta plain fashioned during the Holocene of the quaternary phase by the build-up of sedimentary strata. The area's prominent geological feature is the alluvium of sediments within the sub-equatorial tropical region, covering the majority of the Niger Delta (Figure 2). Also, the area is characterized by distinct wet and dry seasons Agbalagba et al. (2013) which constitute a prolonged period of rainfall as well as an extended period of harmattan Ugya AY et al. (2018). The district constitutes about 7.6% of Nigeria's all-out landmass, and more than 25 million individuals occupy it in the south southern states of Nigeria.

3.2. Data Collection

Landsat 7 was obtained from the US Geological Survey Agency (USGS) between 1/10/2020 to 1/04/2015 via Earth Explorer (https://earthexplorer.usgs.gov/) and was loaded into ArcGIS for analysis. A total of 26 areas was digitized involving the terrestrial and the aquatic environment and were classified as Land/Vegetation, Urban, and River. More so, an aggregate of thirty-six (36) specimens for water and soil were collected from six different locations within the study area (possible affected areas from the vegetation analysis), with more focus on oil spill sites such as farmland, riverbank, towns, and remote location for bulk soil sample collection. Six different samples from each location made up the total samples used for this analysis with the six locations represented with the letters A (river bank), B (fish pond), C (farmland), D (river bank), E (fish pond), and F (remote area). The soil specimens were gathered two-fold for nuclear retention spectrophotometer (AAS), while the water samples were gotten from a location directly connected to the oil and gas activities, such as lakes, farmland, etc. within the study area. The collected soil samples were placed in a white polythene bag while the water samples were collected in a sterilized 1.5-litre container with a tight-fitting cock. Both samples were then labelled to differentiate collection locations and subsequently, the samples were placed in a cooler to ensure temperature stability.

Radiation inspector equipment and an atomic absorption spectrophotometer (Figure 3) were used to detect the radioactivity concentration rate as well as heavy metal content of the collected samples. The radiation inspector was placed on the measuring cylinder without close contact with the sample to avoid an increase in intensity. This, therefore, enabled adequate analysis measure in counts per minute. For the Atomic Absorption Spectrophotometer experiment, the specimens were vaporized in flame before analysis for heavy metal, and subsequent output was sent to the system for results interpretation. Additionally, the level of acidity and alkalinity of samples were measured using the Ph meter which was calibrated at the beginning of the experiment at the buffer solution between Ph values of 4.00 and 10.00 after which it was rinsed with distilled water to remove traces of the solution being used.

Figure 3. (a) Radiation inspector (b) Atomic absorption spectrophotometer (AAS)

4. Results and Discussion

The NDVI and SAVI results show that the vegetation in Otuokpoti and its environment is unhealthy as the index ranges from -0.23 to 0.14 (light grey) and -0.12 to 0.13 (light green) approximately. However, the numbers closer to 1 indicates healthy vegetation, while numbers below zero are non- vegetation (figure 4). This could indicate that the vegetated area is affected by an oil spill due to industrial activities that are also responsible for increased radionuclide stages and concentration of these waterways, consequently making it unsafe radiologically for consuming as portable water.

Figure 5 also shows the thematic map classification as of the region as well as the training samples used for classification.

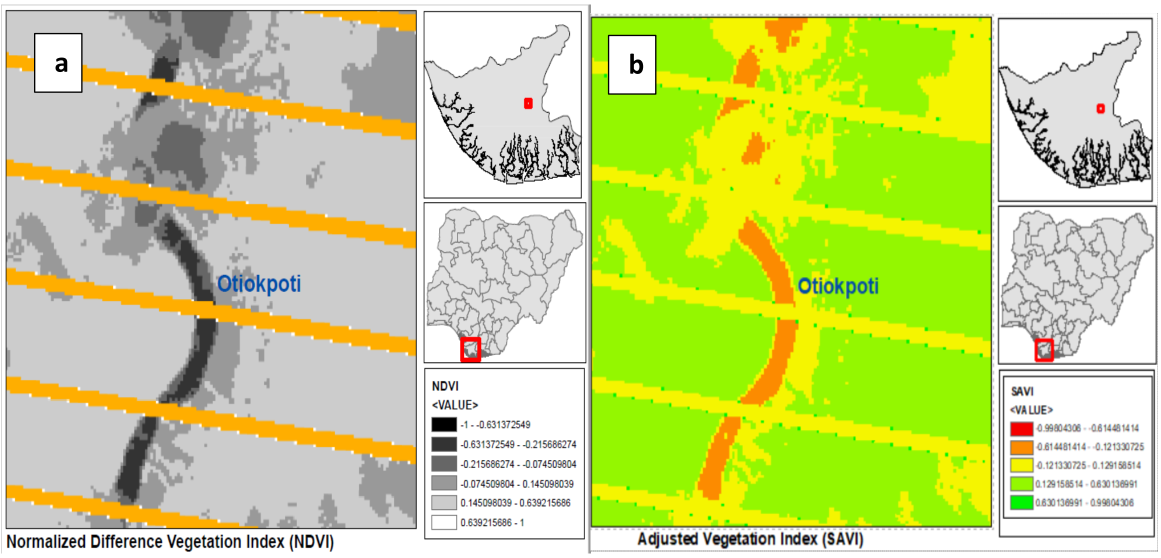
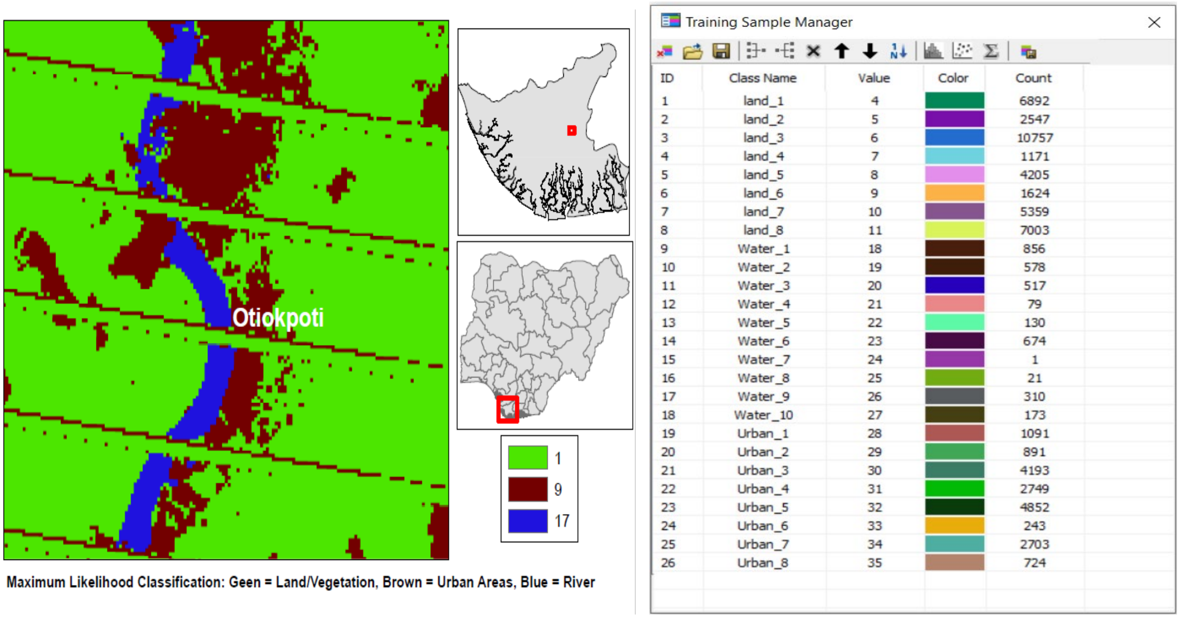


Figure 4. Map of *v*egetation analysis using; (a) NDVI (b) SAVI. Each analysis shows a large portion of unhealthy vegetation in Otuokpoti region.



ID	Class Name	Value	Color	Count
1	land_1	4		6892
2	land_2	5		2547
3	land_3	6		10757
4	land_4	7		1171
5	land_5	8		4205
6	land_6	9		1624
7	land_7	10		5359
8	land_8	11		7003
9	Water_1	18		856
10	Water_2	19		578
11	Water_3	20		517
12	Water_4	21		79
13	Water_5	22		130
14	Water_6	23		674
15	Water_7	24		1
16	Water_8	25		21
17	Water_9	26		310
18	Water_10	27		173
19	Urban_1	28		1091
20	Urban_2	29		891
21	Urban_3	30		4193
22	Urban_4	31		2749
23	Urban_5	32		4852
24	Urban_6	33		243
25	Urban_7	34		2703
26	Urban_8	35		724

Figure 5: (a) Thematic classification map (b) Terrestrial and aquatic region training samples
Note: Vegetation (green), urban areas (brown), and water bodies (blue)

4.1. Graphical Results

The scattered plots from the maximum likelihood classification of the terrestrial and aquatic region show a very strong positive linear, moderate and negative correlation between Band 1, 2, 3, 4, 5, 6, 7, and 8 when plotted against each other, see (figure 6). This was used to determine the relationship between the aquatic (Blue) and the urban (brown) region based on their spectral bands. Band 3 vs band 1, band 3 vs band 2, and band 2 vs band 1 illustrate a very strong linear relationship as shown in the 1st column. Band 8 vs band 4, band 7 vs band 5, and band 5 vs band 4 show moderate correlation while band 6 vs band 2, band 6 vs band 1, and band 6 vs band 3 show a negative correlation.

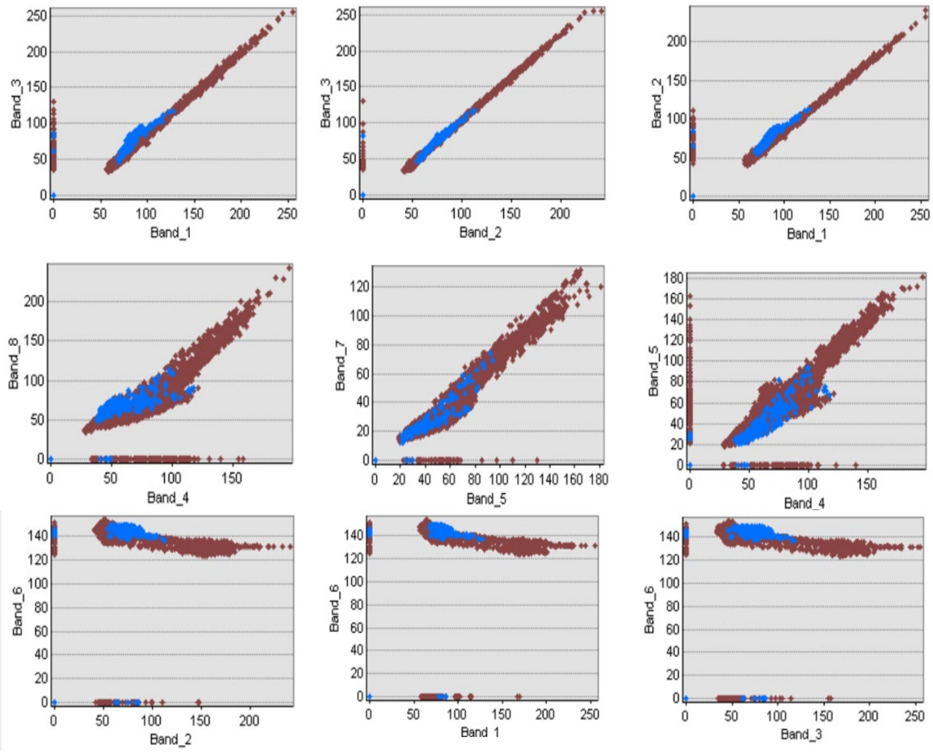


Figure 6: Spectral relationship between urban areas and river

4.2. Validation

Further analysis was carried out in the laboratory to assess the possible cause of the mangrove's poor health condition. The analysis findings on radioactivity concentration on soil and water samples show that the soil's action varies between 39.333Bq/g in location C to 64.667Bq/g in location B, with an average value of 53.389Bq/g as shown in figure 7. The high radiation level value got particularly at area B, which means that human exercises in the region include oil spillage and gas flaring. This affirmed the imminence of oil spillage right now expanded the degree of radionuclides in the examination territory. The water movement went from 38.333Bq/l in area D to 52.000Bq/l in area B with a mean estimation of 44.389Bq/l. The mean radiation level for the water sample (44.389Bq/l) is far above the WHO endorsed the practical value of radioactivity in water for consumption Botwe et al. (2017).

Figure 7 shows a considerable and appreciative count of ionizing radiation in both samples but more in the aquatic region (A, B, and D).

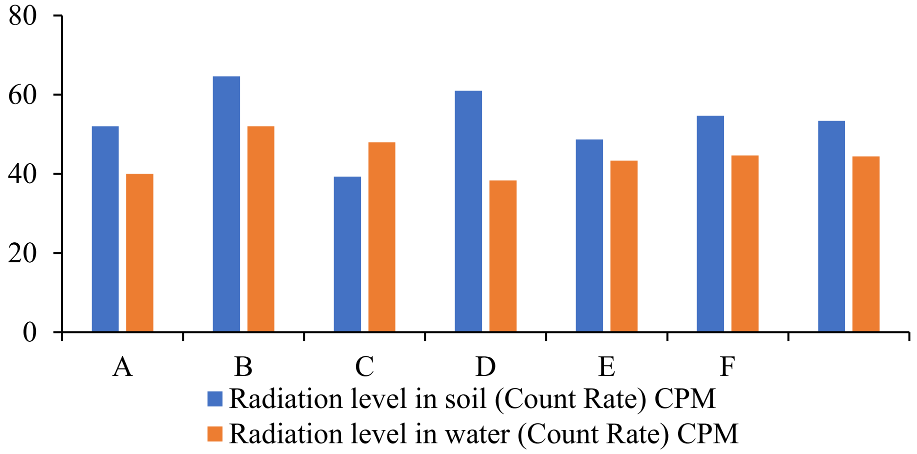


Figure 7. The radiation level in soil & water sample

Additionally, Table 1 illustrates the pH and the physic-chemical parameters concentration samples where Zn was identified to dominate soil and Fe in water, respectively. The soil sample's pH averaged between 8.4-8.71 alkaline with a mean value of 8.62 while the water sample was found to be between 5.2 acidic to 7.6 alkalines with an average of 6.41 which is indicated in figure 8. The average values of Lead (pb), Iron (Fe), and Zinc (Zn) were respectively 0.015mg/l, 9.9mg/l, and 0.095mg/l all of which except Iron were contained by the certified values for clean soil. However, the degree of Lead obtained in the water samples portends potential hazards as possibly leading to pb poison Figueiredo et al. (2019).

Table 1. Average physic-chemical parameters concentration in soil & water samples

		Soil Sample				**Water Sample**			
S/N	Location code	pH	Pb mg/kg	Zn mg/kg	Fe mg/kg	pH	Pb mg/l	Fe mg/l	Zn mg/l
1	A	8.4	37.30	101.30	46.80	6.8	0.01	1.69	0.04
2	B	8.71	35.30	103.16	50.43	6.4	0.02	18.11	0.15
3	C	8.70	-	-	-	5.2	-	-	-
4	D	8.64	-	-	-	6.4	-	-	-
5	E	8.61	-	-	-	6.1	-	-	-
6	F	8.64	-	-	-	7.6	-	-	-
	Average	8.62	36.30	102.23	32.41	6.41	0.015	9.9	0.095
	WHO Limit	6.5-8.5	2.00	0.60	-	6.5-8.5	0.001	0.300	5.00

Similarly, the mean value for Lead (pb), Zinc (Zn), and Iron (Fe) content of the water sample is 36.30mg/l, 102.23mg/l, and 32.41mg/l respectively in Location A and B. Generally, the Niger Delta Region is known to have an appreciative concentration of Iron. According to Okiongbo and Douglas (2015), the enhanced concentration of Iron in surface and groundwater can be attributed to pyrite's oxidation and leaching of iron-bearing minerals.

However, the high percentage of Iron concentration can also result from the presence of petroleum fly ash as combustion of fuels containing metals can lead to the formation of low melting-point compounds that are corrosive to metal parts and the domain geochemical contents Drews (2008). Excess Iron in the human body can be because of many health issues such as liver disease, diabetes mellitus, chronic fatigue, and damage to the skin cells.

Figure 8 shows the highest concentration of the soil sample element to be Zinc (55%) while Lead and Iron are 20% and 25% respectively. Although Zinc's high percentage indicates organic matter availability, as it is an important micronutrient of plant growth. However, research has shown that Zinc levels as low as 100 – 200 mg/kg can cause poor plant growth (Jaganathan et al., 2018). Therefore, the results in location A and B showed a zinc concentration of 101.30mg/kg and 103.16mg/kg, which indicates pollution which may arise due to spills in the location. However, Water samples also had values of 0.04 to 0.15mg/l with an average value of 0.095mg/l which is unsuitable for domestic use.

The possible sources of Lead in the sample are burnt gasoline and crude oil. Contamination by elevated levels of Lead is likely to be of great harm not exclusively to the soil yet also to the sea-going creature as flowing water from soil surfaces is released into aquatic bodies and long-haul amassing could result in unfriendly impact Bhuyan et al. (2017).

A relapse examination on heavy metals and gross movement concentration illustrates a reliable connection between the metals analyzed and radiation grouping in water and soil. This indicated the nearness of these metals have an immediate holding for the degree of the radioactive nuclide in the environment (Yi et al., 2017)

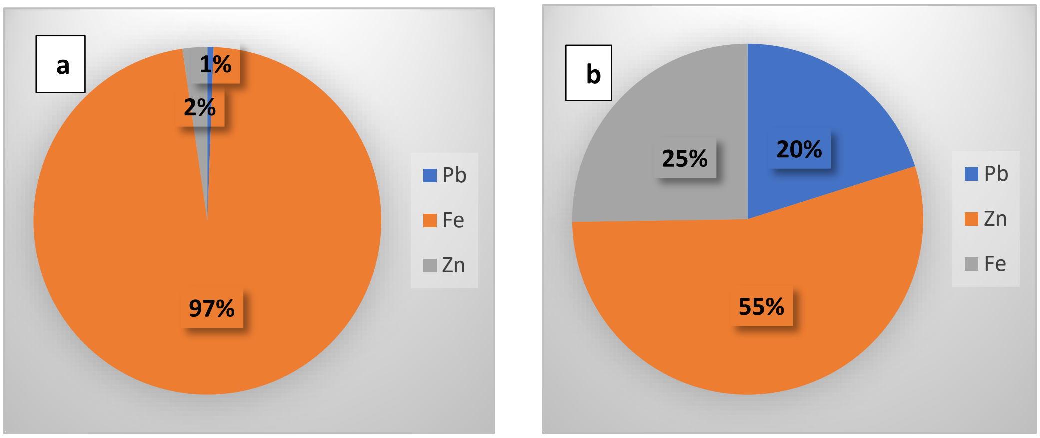


Figure 8: Percentage of chemical concentration in (a) Soil (mg/kg), (b) Water mg/l

5. Conclusion

From the presented analysis, The NDVI and SAVI show that a good portion of the mangrove in Otuokpoti possesses ill vegetation. All the sampled locations within the study area were affected by the oil spillage in the study area, which has caused increased radionuclides and heavy metals in the area which exceeded the WHO recommended limit.

There were fluctuations in the level of heavy metals analyzed from positions as shown in the diversity of radionuclide substance in water and soil specimen and was chiefly of biological basis. The increased presence of metals like Pb^{2+} in the specimen containing water shows that the water is polluted and unsafe for domestic or agricultural use. This, therefore, requires strategic policies such as proper clean-up and other Impact mitigation measures (IMM) in the event of oil spillage, regular monitoring of the radiation level, and enforcing environmental legislation to reduce drastic effects to the public.

References

Adewumi, A. A. (2016). Determination of Excess Lifetime Cancer Risk Due to Gamma Radiation in Some Agricultural Products Obtained From Two Oil Fields in the Niger Delta Region of Nigeria. *International Journal of Science and Research (IJSR)*.

Agbalagba, E., Avwiri, G., & Chadumoren, Y. (2013). Gross &#945 and &#946 Activity Concentration and Estimation of Adults and Infants Dose intake in Surface and Ground Water of Ten Oil Fields Environment in Western Niger Delta of Nigeria. *Journal of Applied Sciences and Environmental Management*. https://doi.org/10.4314/jasem.v17i2.10

Bhuyan, M. S., Bakar, M. A., Akhtar, A., Hossain, M. B., Ali, M. M., & Islam, M. S. (2017). Heavy metal contamination in surface water and sediment of the Meghna River, Bangladesh. *Environmental Nanotechnology, Monitoring and Management*. https://doi.org/10.1016/j.enmm.2017.10.003

Botwe, B. O., Schirone, A., Delbono, I., Barsanti, M., Delfanti, R., Kelderman, P., Nyarko, E., & Lens, P. N. L. (2017). Radioactivity concentrations and their radiological significance in sediments of the Tema Harbour (Greater Accra, Ghana). *Journal of Radiation Research and Applied Sciences*. https://doi.org/10.1016/j.jrras.2016.12.002

Carolin, C. F., Kumar, P. S., Saravanan, A., Joshiba, G. J., & Naushad, M. (2017). Efficient techniques for the removal of toxic heavy metals from aquatic environment: A review. In *Journal of Environmental Chemical Engineering*. https://doi.org/10.1016/j.jece.2017.05.029

Chinedu, E., & Chukwuemeka, C. K. (2018). Oil spillage and heavy metals toxicity risk in the Niger Delta, Nigeria. *Journal of Health and Pollution*. https://doi.org/10.5696/2156-9614-8.19.180905

Coppock, R. W., & Christian, R. G. (2018). Petroleum. In *Veterinary Toxicology: Basic and Clinical Principles: Third Edition*. https://doi.org/10.1016/B978-0-12-811410-0.00050-7

Drews, A. (2008). Standard Test Methods for Determination of Nickel, Vanadium, Iron, and Sodium in Crude Oils and Residual Fuels by Flame Atomic Absorption Spectrometry. In *Manual on Hydrocarbon Analysis, 6th Edition*. https://doi.org/10.1520/mnl10996m

E. Ite, A., J. Ibok, U., U. Ite, M., & W. Petters, S. (2013). Petroleum Exploration and Production: Past and Present Environmental Issues in the Nigeria's Niger Delta. *American Journal of Environmental Protection*. https://doi.org/10.12691/env-1-4-2

Figueiredo, C. C. de, Chagas, J. K. M., da Silva, J., & Paz-Ferreiro, J. (2019). Short-term effects of a sewage sludge biochar amendment on total and available heavy metal content of a tropical soil. *Geoderma*. https://doi.org/10.1016/j.geoderma.2019.01.052

Goronovski, A., Joyce, P. J., Björklund, A., Finnveden, G., & Tkaczyk, A. H. (2018). Impact assessment of enhanced exposure from Naturally Occurring Radioactive Materials (NORM) within LCA. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2017.11.131

Jaganathan, D., Ramasamy, K., Sellamuthu, G., Jayabalan, S., & Venkataraman, G. (2018). CRISPR for crop improvement: An update review. In *Frontiers in Plant Science*. https://doi.org/10.3389/fpls.2018.00985

Kadafa, A. A. (2012). Oil Exploration and Spillage in the Niger Delta of Nigeria. *Civil and Environmental Research*.

Kovler, K. (2017). The national survey of natural radioactivity in concrete produced in Israel. *Journal of Environmental Radioactivity*. https://doi.org/10.1016/j.jenvrad.2016.03.002

Mao, G., Shi, T., Zhang, S., Crittenden, J., Guo, S., & Du, H. (2018). Bibliometric analysis of insights into soil remediation. *Journal of Soils and Sediments*. https://doi.org/10.1007/s11368-018-1932-4

Okiongbo, K. S., & Douglas, R. K. (2015). Evaluation of major factors influencing the geochemistry of groundwater using graphical and multivariate statistical methods in Yenagoa city, Southern Nigeria. *Applied Water Science*. https://doi.org/10.1007/s13201-014-0166-x

Peter, O., Mohamed, A., Emmanuel, V., & Tochukwu, N. (2020). Corrosion Effects on Low Carbon Steel Marine Heat Exchanger. *International Journal of Advanced Science and Technology*.

U, O., AP, U., KNO, B. M., & IKE, E. (2019). Levels of Selected Heavy Metals in Water and Sediment of the Soku Oil Field Area of the Niger Delta, Nigeria. *Journal of Aquatic Pollution and Toxicology*.

Ugya AY, Ajibade FO, & Ajibade TF. (2018). Water pollution resulting from mining activity: an overview. In *Proceedings of the 2018 Annual Conference of the School of Engineering & Engineering Technology (SEET), The Federal University of Technology, Akure, Nigeria, 17-19 July, 2018*.

Yi, Y., Tang, C., Yi, T., Yang, Z., & Zhang, S. (2017). Health risk assessment of heavy metals in fish and accumulation patterns in food web in the upper Yangtze River, China. *Ecotoxicology and Environmental Safety*. https://doi.org/10.1016/j.ecoenv.2017.07.022

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