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Assessment of Hydrocarbon Content in Mangrove Habitats of Crude Oil Exploration and Artisanal Refining Sites in Degema Oilfield

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Abstract
The study comparatively assessed the hydrocarbon contents of mangrove habitat in selected crude oil exploration communities and artisanal refining sites in Degema Oilfield Rivers State. The study adopted the true-experimental design on twelve (12) randomly selected sampling points including eight (8) soil samples from Crude Oil Exploration Site (COES), two (2) from Artisanal Refining Site (ARS), and two (2) soil samples as the Control. The data collected was analyzed using mean and Analysis of Variance (ANOVA). The study revealed that: Total Hydrocarbon Content (THC) at the COES ranged from 912.45 mg/l to 1,365.63 mg/l in Obuama-Harry, and Bille communities, with Total Petroleum Hydrocarbon (TPH) values of 209.04 mg/l and 114.53 mg/l, respectively obtained at Bille and Obuama-Harry communities. Also, the mean values of 1,142.16 mg/l, and 100.33 mg/l for THC and TPH respectively far exceed the Control (867.30 mg/l and 97.80 mg/l), and the WHO and DPR limits of 20 mg/l for THC and TPH. The study found THC of 1561.58 mg/l, and TPH of 199.91 mg/l at ARS was far higher than the WHO, and DPR limit of 20 mg/l. The study recommended that the Ministries of Petroleum and Environment should enforce stricter penalties on artisanal refiners for bioremediation, phytoremediation, or chemical treatments to degrade or remove hydrocarbons, mitigate soil contamination and ecological damage of the mangrove ecosystems serve as buffers against coastal erosion in communities.

Keywords: Hydrocarbon contents, mangrove habitats, crude oil exploration, artisanal refining, Degema oilfield

Introduction

Mangroves are widely recognized as the dominant shrubs and trees forming plant communities in tidal saline wetlands along subtropical and tropical coasts (Mangrove Action Plan, 2015). Mangrove trees and shrubs typically thrive in shallow, muddy saltwater along seashores and creeks in tropical regions (Alonge, 2016). Similarly, mangroves are coastal wetland plants with unique structural and functional traits based on morphological and eco-physiological characteristics that aid their growth, survival, and adaptability in that environment (Chindah, 2017). The halophytic nature of mangroves and their ability to withstand low oxygen levels in the soil enable them to thrive in coastal swamps (Lovelock et al., 2016). In this regard, mangrove plantations flourish in swampy areas with soils regularly inundated by salty seawater, as seen in the Niger Delta environment (Ugochukwu & Ertel, 2015). This makes the mangrove habitat to thrive in the sensitive brackish water and wetland ecosystem that is home to important flora and fauna as well as crucially driving the local economy, particularly in the Niger Delta region. Mangroves provide human benefits and ecosystem services, including sediment trapping, food provision, and fish nurturing, especially in coastal areas (Mumby et al., 2015). In this light, virtually all coastal communities rely heavily on mangroves for building, heating, cooking, and making huts, fences, furniture, boats, poles, platforms, charcoal, fish traps, and bridges (Kathirensan & Bingham, 2017). Mangrove plants are very crucial to the coastal ecosystem, significantly enhancing coastal fishery growth, preventing erosion, providing habitat for prawns and fish, and serving as protective barriers against storms and tidal surges (Smith & Sorensen, 2014; Revathy & Lakshmi, 2024; Weaver & Stehno, 2024). Additionally, the mangrove habitat effectively provides economic, social, domestic, construction, medicinal, and cultural benefits among other ecosystem services to humans and the environment (Onugha, 2022). The tannin and resins in the mangrove plants are used for dying and leather making while the vegetation is used for herbal medicine (Chindah (2017). In this regard, the mangrove habitat provides ecological benefits including supporting local fisheries, protecting shorelines, and enhancing biodiversity among others that are essential for the well-being of these communities (Murray, 2019**)**. Mangrove

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plants are utilized globally for a variety of activities and purposes, offering traditional, commercial, medicinal, construction, residential, and spiritual benefits (Kumar & Sinha, 2021**)**. Furthermore, mangrove habitat provides ecosystem services like climate regulation, food production, and spiritual support among other benefits for coastal communities (Simbi-Wellington, 2020). This implies that the growth and survival of mangrove plants and fishes in a coastal community like the Degema Local Government Area can be linked to ecosystem services.

Anthropogenic or human-induced activities like crude oil exploration and artisanal refining are synonymous with the continuous release of noxious chemical substances that could accentuate the degradation of the mangroves (Ofoegbu & Akindele, 2021**)**. In this regard, oil spillage escalates the cycle of contamination that distorts the morphological and eco-physiological characteristics as well as degrades the soil hosting the mangrove plant (Alonge, 2016). Accordingly, the degradation of mangroves could impede the significant role they play in carbon sequestration, sinking for carbon dioxide, and mitigating ecosystem alterations (Ukwe et al., 2016). Also, Simbi-Wellington (2020) reiterated that effluents and spills that inevitably or accidentally occur during crude oil exploration and artisanal refining stir the release of noxious substances that can block the root openings that aid the inhalation and growth of the mangrove plant in a coastal environment. Effluents from legal and illegal crude oil extraction contain high levels of dissolved salts, hydrocarbons, heavy metals, organic and inorganic substances, naturally occurring radioactive materials (NORMs), and other toxic chemicals (Nwankwoala & Okwakol, 2016; Otevia, 2018; Aina & Owoade, 2019). Toxic pollutants from crude oil exploration and artisanal refining harm soil, groundwater, mangroves, and biodiversity, worsening human health, poverty, socioeconomic conditions, and underdevelopment in Nigeria's Niger Delta (Binuomoyo & Ogunsola, 2017; Anyakora & Coker, 2018). Alluding to this, Nazmuz-Sakib (2021) observed that the legal exploration of crude oil by registered local and multinational companies as well as illegal artisanal refining of crude oil tends to affect the natural state of the Niger Delta coastal area that is holding between 60-80% of animals species (like monkey, squirrels, barracuda, mudskipper, antelopes, elephants, etc.) and plant species. This aligns with the earlier assertion by Smith and Sorensen (2014) that crude oil exploration has reduced mangrove forests to under 50% of original coverage, with over half degraded, as seen around the Degema oilfield. Furthermore, effluents from corroded pipes and equipment accentuate leaky and ruptured crude oil pipelines heighten the occurrence of spills and the release of substances that increase the concentration of hydrocarbons around crude oil exploration sites, oilfields, and flow stations (Ifelebuegu et al., 2017; Nazmuz-Sakib, 2021). In specificity, artisanal refining (otherwise "*Kpo Fire*" in the local palace) is the exploration of crude oil at a site in locally fabricated metal pipes and drums, underscoring why it is considered an illegal, primitive, and unconventional drilling technique or procedure that is predisposed to the spatial release of toxic hydrocarbon effluents (Akankali et al., 2022). Thus, the discharge of toxic effluents containing hydrocarbons can severely degrade water and soil quality in the Niger Delta, threatening both terrestrial and coastal environments that support mangrove habitats (Osuji & Opiah, 2017; Aina & Owoade, 2019).

Hydrocarbons, composed of hydrogen and carbon, are vital for industries but pose environmental risks when mismanaged. Hydrocarbons, including alkanes, alkenes, and aromatics, are crucial petroleum and natural gas components, essential for energy, fuel, plastics, and chemical production. (Murray, 2019). In oil-rich regions like Niger Delta, hydrocarbons serve as both economic drivers and pollutants, uncontrolled discharges from oil spills, corroded pipes, and artisanal refining cause severe environmental degradation (Ofoegbu & Akindele, 2021). Thus, the entry of hydrocarbons into water bodies or soil can disrupt local ecosystems, degrade water and soil quality, ruin biodiversity, and pose long-term risks to human health and the total environment (Osuji & Opiah, 2017). Hydrocarbons, particularly the more persistent forms such as polycyclic aromatic hydrocarbons (PAHs), accumulate in the soil and sediments, further degrading the natural environment. The persistence of these pollutants in the Niger Delta has been well-documented, with studies showing that once introduced, hydrocarbons remain in the environment for extended periods, making remediation efforts challenging (Varjani, 2017). Crude oil exploration accentuates the release of polycyclic aromatic hydrocarbons (PAHs) with toxicity that causes significant pollution, and degrades plants like mangroves in the affected environments (Aina & Owoade, 2019). Also, artisanal refining, or "*Kpo Fire*," as a widespread informal and illegal exploration practice exacerbates this situation by releasing unregulated amounts of hydrocarbons into the air, soil, and water, especially in the Niger Delta region (Ofoegbu & Akindele, 2021).

Hydrocarbons, especially polycyclic aromatic hydrocarbons (PAHs) are persistent in the environment and difficult to break down as they accumulate in both aquatic and terrestrial ecosystems, posing risks to biodiversity, and contributing to long-term contamination (Aina & Owoade, 2019). The interaction of hydrocarbons with sensitive ecosystems, such as mangrove forests, often results in significant losses in biodiversity and ecosystem services, including fisheries, carbon sequestration, and shoreline protection (Dahdouh-Guebas & Koedam, 2015). Equally, hydrocarbon-polluted water bodies lead to reduced fish populations and compromised agricultural soil, causing widespread food insecurity among other socioeconomic implications for communities (Nwankwoala & Okwakol, 2016). Moreover, the health implications for local communities cannot be overlooked, as long-term exposure to hydrocarbons is linked to respiratory issues, cancers, and other chronic health conditions (Aina & Owoade, 2019). The surging level of hydrocarbon contamination also corresponds with the increased level of environmental degradation, biodiversity destruction, and poverty that is rife or experienced in oil-producing communities in the Niger Delta region (Sam et al., 2017). This thus, necessitates efforts to mitigate hydrocarbon pollution through improved regulatory frameworks, stricter enforcement of environmental laws, and the implementation of eco-friendly and cost-effective bioremediation strategies, where natural processes and microorganisms help break down and remove pollutants (Varjani, 2017). This implies that continued monitoring and enforcement are necessary to protect ecosystems vulnerable to hydrocarbon contamination, such as those found in oil-rich regions. However, socio-political factors and economic pressures are among the complexities that continue to pose significant barriers and challenges to effective environmental management and recovery (Opoku et al., 2019; Zhao & Madni, 2021). This is the crux of the study.

Statement of the Problem

The failure of companies (both indigenous and multinational), and individuals to undertake crude oil exploration, and artisanal refining activities respectively, in defiance of the extant environmental laws, guidelines, techniques, legislations and regulations is an imminent problem. Also, the failure of the Nigerian government to effectively enforce compliance with environmental regulations and global best practices in their operations and exploration activities is indeed another problem. These problems exacerbate spills, pipeline leakages, and effluents containing toxic hydrocarbons that accentuate the inevitable occurrence of environmental degradations that were contemplated to be initially mitigated by the adopted environmental regulations. The release of toxic effluents, wastewater, and sediments has increased the unending occurrence of environmental pollution and hazards. Implicitly, the rising level of environmental pollution is indeed a harbinger of the continued degradation of the inherent ecological resources including mangroves. Thus, the degradation of the soils hosting the mangrove habitat leads to the subsequent loss of their social, economic, spiritual, ecological, traditional, aesthetic and medicinal benefits to man, government and environment. It is based on this backdrop that this study assessed the hydrocarbon contents of mangrove habitat in selected crude oil exploration communities and artisanal refining sites in Degema Oilfield Rivers State. This problem can be solved by articulating the following questions:

1. What are the hydrocarbon contents of the soil in the mangrove habitat in the crude oil exploration sites in the Degema oilfield?
2. What are the hydrocarbon contents of the soil in the mangrove habitat in the artisanal refining site in the Degema oilfield?

Objectives of the Study

The objectives of the study are to:

1. ascertain the hydrocarbon contents of the soil in the mangrove habitat in the crude oil exploration sites in the Degema oilfield.
2. determine the hydrocarbon contents of the soil in the mangrove habitat in the artisanal refining site in the Degema oilfield.

Hypothesis

1. There is no significant difference in the hydrocarbon contents of the mangrove habitat in the crude oil exploration sites and artisanal refining sites in the Degema oilfield.

Study Area

Location and Extent: The study was conducted in the Degema oilfield. The Degema oilfield encompasses oil-bearing and exploration communities such as Degema, Bakana, Usokun-Degema, Ogurama, Tombia, Ke, Bille, Obuama, and Bukuma. Spanning 390 square miles (1,011 km²) in Degema Local Government Area, Rivers State, it includes 347 km² of land, 538 km² of water, and 126 km² of built-up area. Also, Geographically, Degema Local Government Area, located in the southern part of Rivers State, sits at Latitude 4°34'27'' N and Longitude 6°56'17'' E, with an elevation of 54 meters (177 feet). Also, in terms of geographical boundaries, Degema Local Government Area is bordered to the north by Asari, Emohua, and Port Harcourt Local Government Areas; to the west by Okrika and Bonny Local Government Areas; to the east by Akuku Toru and Abua/Odual Local Government Areas; and to the south by the Atlantic Ocean (see Figures 1 and 2).

Climate and Weather: In Degema, the wet season is warm and overcast, and the dry season is hot with mostly cloudy skies. Temperatures throughout the year typically range from 71°F to 87°F, seldom falling below 64°F or exceeding 90°F.

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Soil and Vegetation: The Degema oilfield is situated within swamps, tropical rainforests, and riparian wetlands, surrounded by extensive mangroves, oil palms, and raffia palms in nearly every community in the area, contributing to the vast mangrove forest in the region.

Relief, Drainage and Geology: The communities within the Degema oilfield are drained by the Sambreiro River, a tributary of the Niger, along with the New Calabar River and Kra-kra Creek. This hydrological network spans communities such as Ke, Bille, Tombia, Obuama-Harry, Bukuma, and Bakana, defining the area as a riverine with considerable maritime activities.

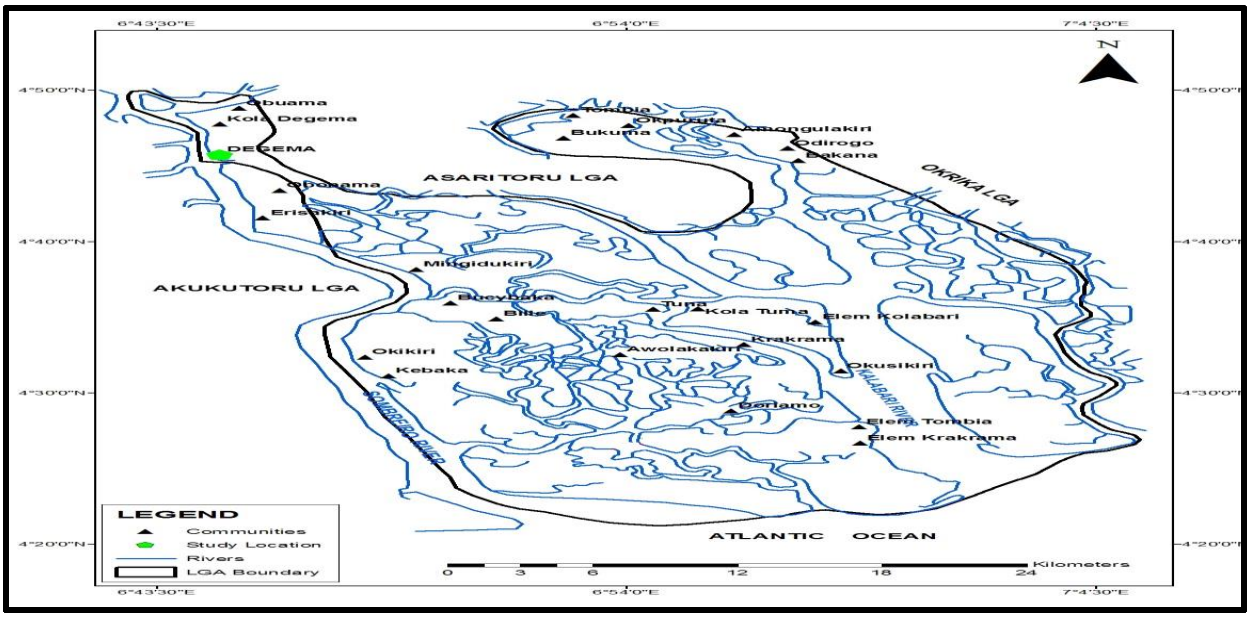

Fig. 1: Degema Local Government Area showing the Communities

Source: Rivers State Ministry of Lands and Housing, 2024.

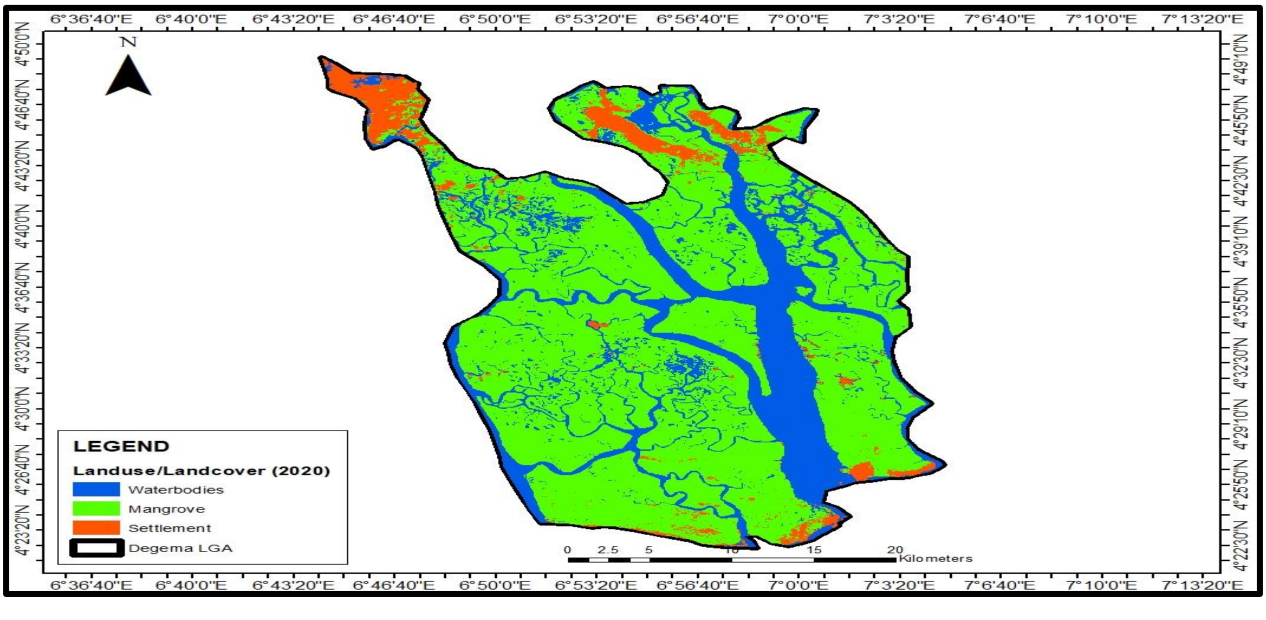

Figure 2: Landuse of Degema showing the Mangrove

Source: Rivers State Ministry of Lands and Housing, 2024.

Population and Economic Activities: Degema Local Government Area has a total population of 285,515 persons across its 17 political wards, and 84 settlements, and (Naluba, 2011). Also, the exploration of crude oil and natural gas in communities such as Bille, Tombia, Ke, Obuama-Harry, Elem-Kalabari, and Bakana appears as the main economic activity for which Degema Local Government Area has gained prominence in Rivers State and the Niger Delta region.

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Methodology
The study adopted the experimental research design. Nwankwo (2016) stated that the experimental research design involved manipulating and controlling intervening variables while addressing various threats to validity, including factors related to subjects, the experimenter, experimental tools, and relevant environmental conditions. The population of the study comprised all the seven (7) communities namely; Ke, Bille, Tombia, Obuama-Harry, Elem-Kalabari, Bukuma, and Bakana that constitutes the Degema oilfield, where crude oil exploration and artisanal refining activities are going on in Degema Local Government Area, Rivers State. Twelve soil samples were collected comprising eight from Crude Oil Exploration Sites (COES), two from the Bille Artisanal Refining Site (BARS), and two control samples. This constituted the sample frame for the study that was conducted in four phases. Firstly, purposive sampling was used to select Obuama-Harry, Bille, Tombia, and Bukuma communities within the Degema oilfield. Secondly, random sampling was used to select two soil samples at. 200 and 500 metres from each of the purposively selected crude oil exploration communities. Thirdly, a purposive sampling technique was used to select two (2) samples from the Bille artisanal refining site. In the fourth and final phase, purposive sampling was used to select two (2) soil samples approximately 1500 m from the Obuama-Harry crude oil exploration site (i.e. the Control). This constituted a sample of 12 soil samples from four communities. Six instruments like Automated Global Positioning System (GPS), measuring tape, masking tape, a field notebook, a Ziploc bag, aluminum foil, and a hand auger were used for the collection soil samples and data in this study.

Soil samples were collected at six sampling points (four COES, 1 ARS, and Control) around the Degema oilfield, using the automated GPS to determine locations. The GPS was used to determine the coordinates wherein the triplicate soil samples were collected using the hand auger at depths of 0-15 cm (topsoil) and 15-30 cm (subsoil) from the six sampling points in the Degema oilfield. The topsoil and sub-soil samples from each of the sampling points were then combined to form one representative soil sample from each of the six sampling points in the Degema oilfield. In addition, the collected soil samples were wrapped in a labeled aluminum foil that was later packed into sealed Ziploc bags to preserve the soil while being conveyed to the laboratory for the determination of hydrocarbons such as Total Hydrocarbon Content (THC), and Total Petroleum Hydrocarbon (TPH). Upon arrival at the laboratory, soil samples were preserved in a refrigerator at 0 to 4 °C before analyzing selected hydrocarbons such as Total Hydrocarbon Content (THC), and Total Petroleum Hydrocarbon (TPH). The soil tests were conducted at the Department of Biology Research Laboratory, Ignatius Ajuru University of Education. The laboratory analysis began with the air or oven drying and chemically digested soil samples, followed by crushing and then sieving them to determine the heavy metals from the soil samples. Also, The soil moisture content was determined gravimetrically by drying samples in an oven at 105°C until a constant weight was achieved (Maiti, 2003; Edori & Iyama, 2017). Relevant Statistical Analytical tools like mean and bar charts were utilized or deplored to answer the research questions, while Analysis of Variance (ANOVA) was used to test the hypothesis at a 0.05 level of significance.

Results

Table 1: Mean Concentration of Hydrocarbon Content of the Soil of the Mangrove Habitat in the Sampled Crude Oil Exploration Sites (COES) in the Degema Oilfield

Sampling Points	**THC (**mg/1)	**TPH (**mg/1)
	$\bar{x}$±SE	**$\bar{x}$±SE**
Obuama-Harry (SP1)	912.45±0.06	114.53±2.09
Bille (SP2)	1365.63±6.39	209.04±0.83
Tombia (SP3)	1279.84±1.09	158.14±0.62
Bukuma (SP4)	1010.24±0.49	126.55±0.10
Pooled Mean for COES	**1142.16±2.01**	**100.33±0.91**
Control (SP6)	867.30±0.26	97.80±0.87
WHO (2017)	20	20
DPR (2011)	20	20

Source: Authors Computation, 2024.

Table 1 shows the results for the hydrocarbon contents of the soil in the Crude Oil Exploration Sites (COES), and Control in the mangrove habitat around the Degema Oilfield including WHO (2017) and DPR (2011) standards for soil hydrocarbons. It further shows that Bille community had the highest THC and TPH levels at 1365.63 mg/l

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and 209.04 mg/l respectively, followed by Tombia community with 1279.84 mg/l (THC) and 158.14 mg/l (TPH). Bukuma community recorded 1010.24 mg/l (THC) and 126.55 mg/l (TPH), while Obuama-Harry community had the lowest values at 912.45 mg/l (THC) and 114.53 mg/l (TPH). Across all sampled points in the Degema oilfield, the mean THC and TPH concentrations of 1142.16 mg/l, and 100.33 mg/l were higher than the THC levels of 867.30 mg/l and TPH levels of 97.80 mg/l recorded at the control (i.e. SP6), indicating lower hydrocarbon content than the that obtained at the crude oil exploration sites. The observed mean THC and TPH concentrations across all sampled sites, including the control, greatly exceed the recommended safe limits set by the World Health Organization (WHO, 2017) and the Department of Petroleum Resources (DPR, 2011), both of which set maximum allowable levels at 20 mg/l. In summary, the hydrocarbon levels in the soil from the Degema oilfield sites are significantly elevated compared to international and national guidelines, indicating contamination from crude oil exploration activities. This suggests potential environmental risks to the mangrove habitat and surrounding biodiversity. The graphical representation of Table 1 was presented in Figure 1 below:

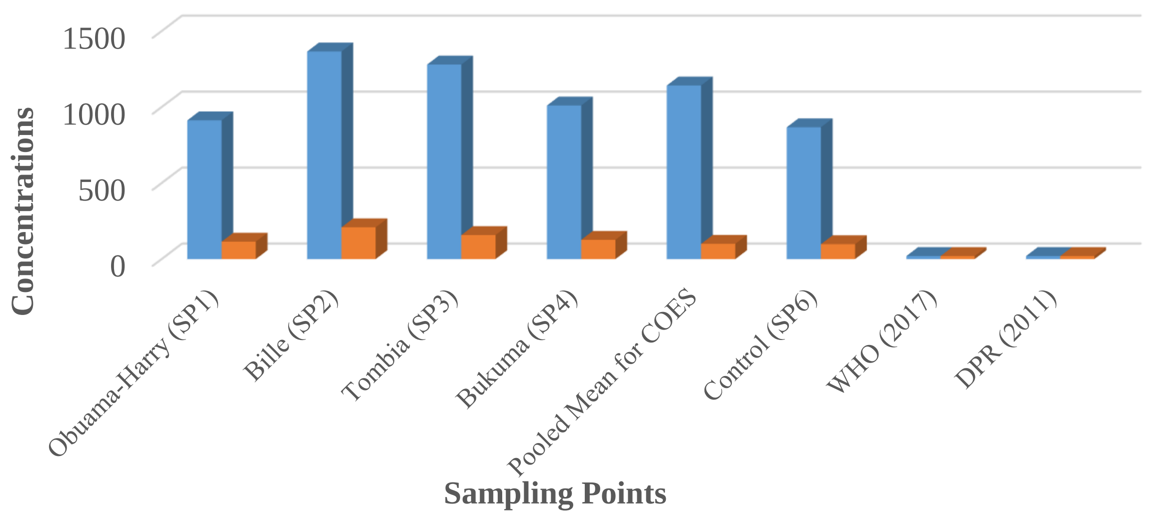

Figure 1: Bar Chart showing Hydrocarbon Content of the Soil of the Mangrove Habitat in the Sampled Crude Oil Exploration Sites (COES) in the Degema Oilfield

Figure 1 shows that the hydrocarbon contents of the soil in the Crude Oil Exploration Sites (COES) include the the Bille community with the highest THC and TPH levels at 1365.63 mg/l and 209.04 mg/l respectively, followed by the Tombia community with 1279.84 mg/l (THC) and 158.14 mg/l (TPH). Bukuma community recorded 1010.24 mg/l (THC) and 126.55 mg/l (TPH), Obuama-Harry community had values at 912.45 mg/l (THC) and 114.53 mg/l (TPH), while the Control had the lowest THC levels of 867.30 mg/l and TPH levels of 97.80 mg/l. The values in the COES and Control were all higher than the WHO/DPR limit of 20 mg/l for hydrocarbons in soil.

Table 2: Mean Concentration of Hydrocarbon Content of the Soil of the Mangrove Habitat in the Sampled Bille Artisanal Refining Site (BARS) in the Degema Oilfield

Sampling Points	**THC** (mg/1)	**TPH** (mg/1)
	$\bar{x}$±SE	**$\bar{x}$±SE**
Bille Artisanal Refinery Site (SP5)	1561.58±1.76	199.91±0.48
Control (SP6)	867.30±0.26	97.80±0.87
WHO (2017)	20	20
DPR (2011)	20	20

Source: Authors Computation, 2024

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Table 2 shows the results for the hydrocarbons of the soil in the Bille Artisanal Refinery Site (BARS) and Control in the mangrove habitat in the Degema Oilfield including WHO (2017) and DPR (2011) standards for soil hydrocarbons. It further shows that the Bille Artisanal Refining Site (BARS) i.e. SP5 had a Total Hydrocarbon Content (THC) of 1561.58 mg/l, and Total Petroleum Hydrocarbon (TPH) of 199.91 mg/l. In contrast, the control (SP6) recorded significantly lower THC and TPH concentrations, with values of 867.30 mg/l and 97.80 mg/l, respectively. Both measurements from the artisanal refining site substantially exceed the WHO (2017) and DPR (2011) permissible limit of 20 mg/l for THC and TPH in the soil. This data suggests that artisanal refining activities contribute to high hydrocarbon contamination in the soil, raising concerns for the health and sustainability of the surrounding mangrove habitat. The graphical representation of Table 2 is presented in Figure 2 below:

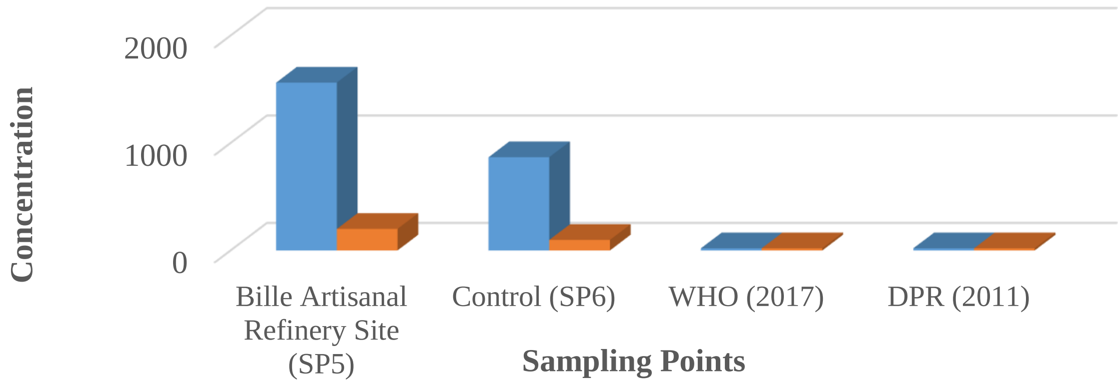

Figure 2: Bar Chart showing Hydrocarbon Content of the Soil of the Mangrove Habitat in the Sampled Bille Artisanal Refining Site (BARS) in the Degema Oilfield

Hypothesis 1: There is no significant difference in the hydrocarbon contents of the mangrove habitat in the crude oil exploration sites and artisanal refining sites in the Degema oilfield.

Table 3: Summary of Analysis of Variance (ANOVA) on the difference in the hydrocarbon contents of the mangrove habitat in the crude oil exploration sites and artisanal refining sites in the Degema oilfield

Parameters	THC			TPH		
	F	**p-value**	**Decision**	**F**	**p-value**	**Decision**
Source of Variation	10716.765	0.000	S	1972.083	0.000	S

Decision rule: *If p<.05 reject Ho, else retain Ho., S= significant, p<.05, NS= Not Significant, p>.05*

Table 3 shows the summary of the Analysis of Variance (ANOVA) on the difference in the hydrocarbon contents of the mangrove habitat in the crude oil exploration sites (COES), and artisanal refining sites (ARS) in the Degema oilfield. It further shows that there is a significant difference in the content of: Total Hydrocarbon Content (THC), and Total Petroleum Hydrocarbon (TPH) at COES (Table 1), and ARS (Table 2) above.

Discussion

The result in Table 1 revealed a mean THC of 1,142.16 mg/l, and mean TPH of 100.33 mg/l obtained at the Crude Oil Exploration Sites (COES) slightly exceeded the Control with 867.30 mg/l and 97.80 mg/l respectively, and far exceeded the WHO and DPR acceptable limits of 20 mg/l for THC and TPH in the soil. This finding is consistent with the research by Uche et al. (2024) that observed elevated hydrocarbon levels that adversely affected soil quality and biodiversity. This finding aligns with Ekong et al. (2022) that prolonged exposure to high hydrocarbon concentrations can lead to soil degradation and loss of ecosystem functions, particularly in sensitive mangrove habitats that serve as critical ecological buffers and breeding grounds for various species). Additionally, the implications of this finding agree with Obi et al. (2023) that high hydrocarbon accumulation associated with oil pollution poses a significant risk to public health and ecological integrity in space.

Table 2 revealed that artisanal refining activities contribute to high hydrocarbon (THC and TPH) contamination in the soil, above the levels at the Control, and the WHO and DPR permissible limits for soil hydrocarbons. This finding is consistent with Tudararo-Aherobo and Fakunle (2023) that illegal refining is attributed to heavy hydrocarbon contamination levels, which have been observed to deteriorate soil quality and disrupt the microbial and ecological balance in the Niger Delta. Also, this finding aligns with (Ogunfowokan et al., 2022; Raimi et al., 2022) that high hydrocarbon levels result in reduced soil fertility, impacting agricultural productivity and increasing the risk of heavy metal bioaccumulation, which poses long-term risks to public health and biodiversity in the area. This finding is consistent with Obiezu and Alozie (2023) study of similar artisanal refinery impacts in Nigeria have highlighted the persistence of hydrocarbons in the environment, stressing the need for stringent environmental monitoring and remediation practices to mitigate these effects that raise concerns for the health and sustainability of the surrounding mangrove habitat in the Degema oilfield.

Table 3 revealed significant differences in Total Hydrocarbon Content (THC), and Total Petroleum Hydrocarbon (TPH) at the Crude Oil Exploration Sites (COES), and Bille Artisanal Refining Site (BARS) in Degema oilfield. These findings align with the previous finding by Uche et al. (2024) that hydrocarbon contamination and impacts from crude oil exploration and artisanal refining activities differ and pose serious risks to the ecological integrity and health of mangrove habitats, which are vital for biodiversity and coastal protection. Also, this finding agrees with Ekong et al. (2022) that the varying levels of degradation of mangrove ecosystems from crude oil exploration and artisanal refining can lead to loss of habitat for various species and disrupt essential ecosystem services.

Conclusion

The study concludes that crude oil exploration and artisanal refining activities heightened the incidence of high hydrocarbon concentrations in the soils hosting the mangrove habitats around the Degema Oilfield raising significant environmental concerns. Thus, this analysis highlights the critical need for regulatory action and restoration initiatives to address soil contamination levels from hydrocarbons that exceed permissible standards by nearly 80 times in the Bille area, illustrating the broader implications for environmental health from artisanal refining activities.

Recommendations

Based on the findings of the study, the following recommendations were proffered:

1. The government should mandate comprehensive environmental and social impact assessments that would incorporate effective environmental management strategies like sustainable resource management, pollution prevention programmes, habitat restoration, and integrated waste management like reduction, reuse, and recycling in order to mitigate hydrocarbon pollution, protect vulnerable ecosystems, and ensure sustainable development in oil exploration areas.
2. The Ministries of Petroleum and Environment should enforce stricter penalties on artisanal refiners for bioremediation, phytoremediation, or chemical treatments to degrade or remove hydrocarbons, mitigate soil contamination and ecological damage of the mangrove ecosystems serve as buffers against coastal erosion in communities.
3. The Nigeria National Petroleum Company Limited (NNPCL) should ensure that oil companies comply with waste management, resource conservation, soil rehabilitation, use of cleaner technologies, and environmental sustainability initiatives aimed at reducing or eliminating the release of pollutants that harm the water, marine, forest, and atmospheric resources in the crude oil and artisanal refining environments.

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