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Assessment of Heavy Metal Contamination in Mangrove Habitats of Crude Oil Exploration and Artisanal Refining Sites in Degema Oilfield

***Okwakpam, I. O., Barango, S. L., & Onugha, A. C.**
Department of Geography and Environmental Studies, Ignatius Ajuru University of Education, Port Harcourt, Nigeria

***Corresponding author email**: ikechiokwas52@gmail.com

Abstract
The study assessed the heavy mental contents of mangrove habitat in selected crude oil exploration sites and an artisanal refining site in Degema Oilfield Rivers State. The study adopted the true-experimental design on twelve (12) sampling points out of which eight (8) soil samples were from the Crude Oil Exploration Site (COES), two (2) soil samples from Artisanal Refining Site (ARS), and two (2) soil samples as the Control were randomly collected in triplicates and composited. The data collected was analyzed using mean and Analysis of Variance (ANOVA). The study revealed that: Cadmium (Cd) concentration (2.80 mg/L) at Bukuma community was significantly higher than all other sampling points. Also, Pb, Cd, Fe, and Cu concentrations of 0.49 mg/L, 1.34 mg/L, 21.75 mg/L, and44.64 mg/L respectively at the artisanal refining site are significantly higher than the control (0.07 mg/L), WHO (2017) limit of 3.0, 0.01, 0.003, and 0.003 for Pb, Cd, Fe, and Cu respectively in soil. Hence, the result concluded that Crude oil extraction increases the concentration of harmful heavy metals in mangroves, highlighting the need for targeted interventions to reduce pollution and human health effects. The study recommended that The Nigeria Environmental Society should collaborate with governments to monitor companies' compliance with operating standards to reduce the discharge of untreated effluents containing heavy metals that harm mangroves, biodiversity, and contaminate food and water sources as well as harm human health.

Keywords: Heavy Metal Contents, Mangrove Habitats, Crude Oil Exploration, Artisanal Refining, Degema Oilfield

Introduction

Mangroves are dominant shrubs and trees that thrive in shallow, muddy, and tidal saline wetlands, primarily found in seashores and creeks in subtropical and tropical coastal environments (Mangrove Action Plan, 2015; Alonge, 2016). Mangrove habitats provide numerous economic, social, medicinal, construction, and cultural benefits, along with essential ecosystem services for humans and the environment (Onugha, 2022). In this light, Mumby et al. (2015) stated that the mangrove plant provides significant human benefits, including food supply, fish habitat, and sediment trapping, alongside its vital ecosystem functions, especially in coastal areas. This implies that the mangrove habitat provides essential benefits to communities around the Degema oilfield in Nigeria's Niger Delta, supporting both their livelihoods and the local ecosystem. The halophytic nature of mangroves and their ability to survive low oxygen levels in coastal swamps contribute significantly to fisheries, prevent erosion, and provide barriers against storms and tidal surges (Choudhry, 2007; Smith & Sorensen, 2014). Also, Ugochukwu and Ertel (2015) reiterated that mangrove forests thrive in swampy, saltwater-inundated soils of the Niger Delta, flourishing in sensitive brackish ecosystems that are vital for the local economy and support diverse flora and fauna. Thus, the illegitimate and legitimate crude oil exploration, alongside artisanal refining carried out in defiance of standardized regulations, can lead to oil spills, pipeline leaks, gas flares, and untreated effluents, resulting in air pollution and environmental degradation that may likely diminish and extinct the vast mangrove habitats (Sibe et al., 2019).

The continuous release of chemicals increases mangrove degradation, undermining their vital roles in carbon sequestration and mitigating ecosystem alterations in the environment (Ukwe et al., 2016). Alonge (2016) observed that the morphological and eco-physiological characteristics of mangrove plants can be distorted by contamination from oil spills, chemical effluents, etc. which affects the soil they grow in. Also, Simbi-Wellington (2020) reiterated that effluents and spills from crude oil exploration can obstruct the root openings necessary for the inhalation and growth of mangrove plants in coastal areas, resulting in the degradation of these essential resources. Thus, the composition of effluents from oilfields contains high levels of dissolved salts, hydrocarbons,

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heavy metals, naturally occurring radioactive materials (NORMs), and chemicals used during oil extraction (Otevia, 2018). This could imply the Degema oilfield.

The pollution from toxic chemicals generated from oil spills and effluent discharges could adversely impact the soil, groundwater, and mangrove vegetation among other biodiversity in the environment especially in Nigeria's Niger Delta region (Anyakora & Coker, 2018). This standpoint aligns with the earlier assertion by Smith and Sorensen (2014) that due to crude oil exploration activities, the mangrove forest is at present declining to less than 50% of its initial coverage, and over 50% of what is left is degraded and not adequately productive globally. Also, Nazmuz-Sakib (2021) stated that the exploration of crude oil especially in the Niger Delta states from February 1958 in Oloibiri oilfield and afterward in the Degema oilfield has affected the natural state of this coastal area that is holding between 60-80% of animals species (like monkeys, squirrels, barracuda, mudskipper, antelopes, tortoises, elephants, etc.) and the mangrove plants in Nigeria. The effluents discharged during oil exploration activities as well as crude oil spillage from leaking and ruptured crude oil pipelines will increase the physicochemical characteristics in the environment (Ifelebuegu et al., 2017). Also, the impact of oil and gas exploration activities leads to the discharge of toxic heavy metals that consequentially impact the development of the natural environment as well as its inherent flora (like mangrove plants) and fauna like monkeys, squirrels, rabbits, mudskippers, antelopes, elephants in the Niger Delta region of Nigeria (Nazmuz-Sakib, 2021). The accumulation of heavy metals in fish poses serious threats to aquatic life, human health, and the important part fish plays in the food chain (Hossain et al., 2019). The enunciated effects of oil exploration could also imply the mangroves around the Degema oilfield.

Heavy metals are naturally occurring elements that do not degrade but persist in the ecosystem at high density, toxic to organisms at certain concentrations (Tchounwou et al., 2012; Alloway, 2013). Common heavy metals include lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), and zinc (Zn), all of which are widespread environmental pollutants due to increasing industrialization, mining, and agricultural activities (Ali et al., 2019). In specificity, the accumulation of metals in water, soil, and organisms can disrupt biological processes and lead to detrimental environmental and health outcomes and risks for plants (like mangroves), wildlife, and humans (Hossain et al., 2019). Also, the varying industrial, agricultural, and mining activities trigger the release of noxious metals that do not degrade but pose long-term toxicity risks to aquatic life and human health (Lee et al., 2023). Also, the activities and operations of artisanal refining refineries accentuated high levels of heavy metals like Copper, Chromium, and Lead concentration and contamination in the soils in the Niger Delta region, Southern Nigeria (Njoku et al., 2016). Implicitly, the economic benefits of crude oil exploration are overshadowed by toxic effluents that severely affect fishing and farming activities near oilfields (Akakpo et al., 2018). Also, illegal discharge of untreated effluence and oil spills from crude oil exploration processes and activities result in distressing health and ecological consequences like the destruction of mangrove habitats that had persisted for decades in the Niger Delta (Jiang et al., 2020). Thus, all these malfeasances are aggravated by the failure of the government to effectively enforce its policy framework which provides for the adoption of global best practices during crude oil exploration activities is indeed antithetical to the realization of the goal of a sustainable environment in the Niger Delta region (Binuomoyo & Ogunsola, 2017; Adeola et al., 2022). The poor regulation and unorthodox activities make the heat and effluents generated during the distillation processes and condensation operations in artisanal refineries seriously affect microbial loads and degrade or even exterminate the biodiversity in the soil, water bodies and other environmental components (Ojirika et al., 2019).

Statement of the Problem

Crude oil exploration and artisanal refining involve drilling, seismic surveys, refining, lubrication, and pipeline transportation activities. Conventionally, these activities must comply with laws, guidelines, and regulations to prevent oil spills, pipeline leaks, and toxic chemical discharges that can degrade the environment. Yet, despite these rules, The failure of both indigenous and multinational oil companies in the Niger Delta to follow global best practices in environmental compliance remains problematic. This problem could worsen the environmental degradation initially intended to be mitigated by regulations. Also, the failure of the Nigerian government to enforce oil companies' compliance with environmental regulations and global best practices is problematic. This problem has worsened the uncontrolled release of toxic effluents, wastewater, and sediments, increasing environmental pollution. Implicitly, the rising level of untreated effluent discharge, poor regulatory enforcement, and environmental pollution is a precursor to the continued degradation of the inherent ecological resources including mangroves. Thus, the degradation of mangrove habitats results in the loss of their social, economic, spiritual, ecological, traditional, aesthetic, and medicinal benefits to humans, governments, and the environment. Based on this backdrop this study assessed the heavy metal contents of mangrove habitat in crude oil exploration sites and artisanal refining sites in Degema oilfield Rivers State. This problem can be solved by articulating the following questions:

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i. What are the heavy metal contents of the soil in the mangrove habitat in the crude oil exploration sites in the Degema oilfield?
ii. What are the heavy metal 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 heavy metal contents of the soil in the mangrove habitat in the crude oil exploration sites in the Degema oilfield.
2. determine the heavy metal 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 heavy metal 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 currently comprises oil-bearing and exploration communities like Degema, Bakana, Usokun-Degema, Ogurama, Tombia, Ke, Bille, Obuama, and Bukuma. In terms of size, the Degema oilfield located in Degema Local Government Area, Rivers State is 390 sq mi (1,011 km^2), out of this, land covers 347 km^2, water covers 538 km^2, while the built-up area is 126 km^2. Also, Geographically, Degema Local Government Area, which is situated at the southern part of Rivers State lies along Latitude 4° 34' 27" North and Longitude 6° 56' 17" East with an Elevation of 54 metres (177 feet). Furthermore, in terms of geographical boundaries, Degema Local Government Area is bounded by Asari, Emohua, and Port Harcourt Local Government Areas on the North, Okrika, and Bonny Local Government Areas on the West, Akuku Toru and Abua/Odual Local Government Areas on the East while the Atlantic Ocean is on the South (see Figures 1 and 2).

Climate and Weather: In Degema, the wet season is warm and overcast, while the dry season is hot and mostly cloudy. Year-round, temperatures range between 71°F and 87°F, rarely dipping below 64°F or rising above 90°F

Soil and Vegetation: The Degema oilfield is located in swamps, tropical rainforests, and riparian wetlands, surrounded by abundant mangroves, oil palms, and raffia palms across nearly all communities within the oilfield area. This accounts for the vast mangrove forest in the study area.

Relief, Drainage and Geology: The Degema oilfield communities are drained by the Sambreiro River, a Niger outlet, along with the New Calabar River and Kra-kra Creek. This hydrological setting includes communities like Ke, Bille, Tombia, Obuama-Harry, Bukuma, and Bakana, designating the area as riverine with significant maritime activities.

Population and Economic Activities: Degema Local Government Area has gained importance due to the exploitation of crude oil and natural gas in communities such as Bille, Tombia, Ke, Obuama-Harry, Elem-Kalabari, and Bakana. This prominence places Degema at the forefront of discussions on crude oil exploration in Nigeria's Niger Delta region. Degema Local Government Area, according to Naluba (2011), is in Rivers State's Rivers West Senatorial District, comprising 17 political wards, 84 settlements, and a population of 285,515. Thus, the representation of the communities in Degema Local Government Area was represented in Figure 1 below, while the Land use land cover map of Degema Local Government Area showing the spatial extent of the mangrove habitat was presented in Figure 2 below.

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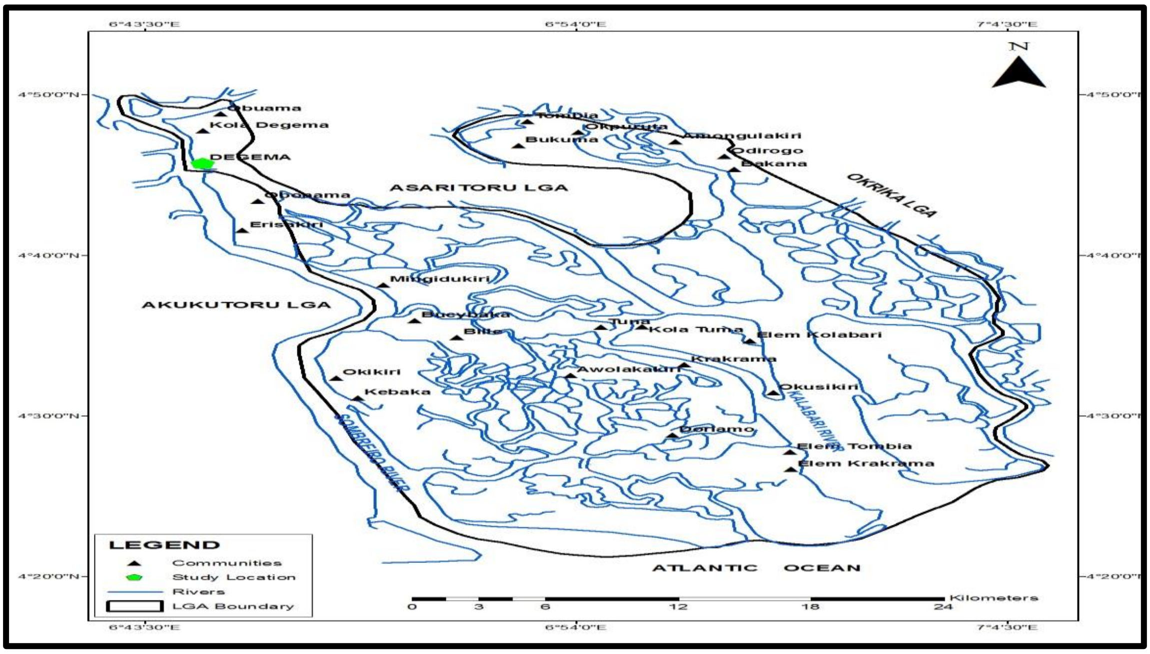

Fig. 1: Degema Local Government Area showing the Communities
Source: Rivers State Ministry of Lands and Housing, 2024.

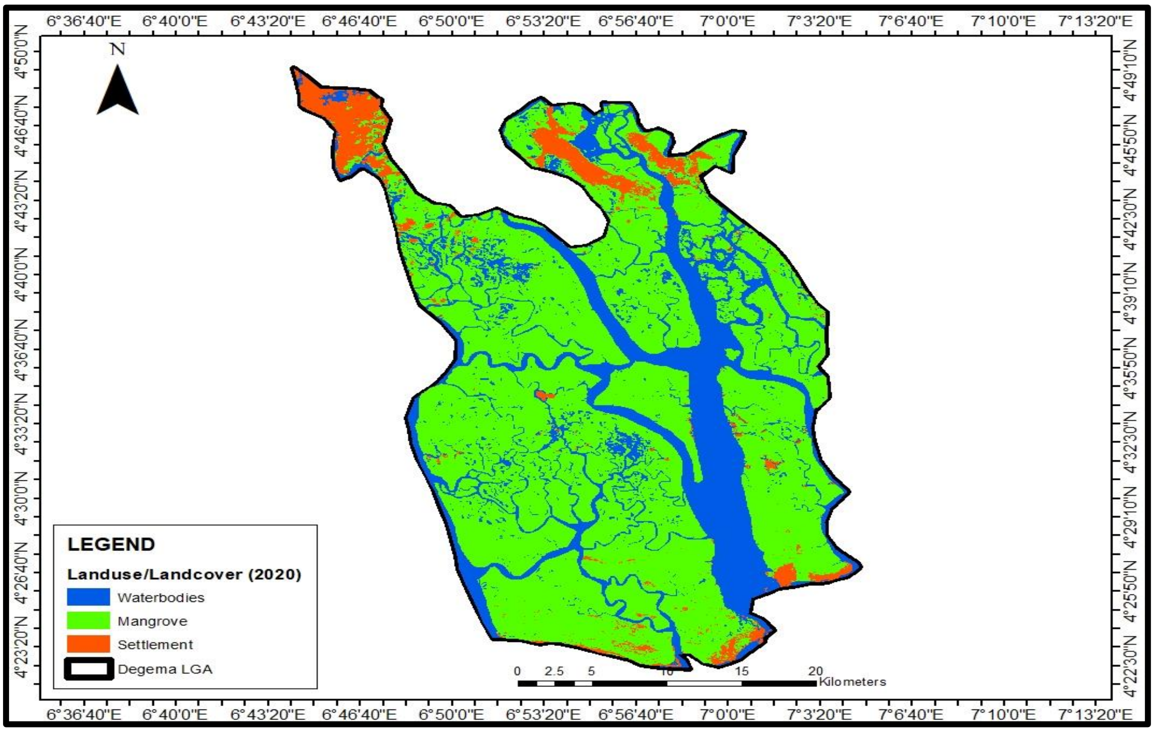

Figure 2: Landuse/Landcover of Degema showing the Mangrove
Source: Rivers State Ministry of Lands and Housing, 2024.

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 includes all seven (7) communities namely; Ke, Bille, Tombia, Obuama-Harry, Elem-Kalabari, Bukuma, and Bakana where crude oil exploration activities are going on and also constitutes the Degema oilfield in Degema Local Government Area of Rivers State. Sample and Sampling Technique: Twelve soil samples were collected: eight from Crude Oil Exploration Sites (COES), two from the Bille Artisanal Refining Site (BARS), and two control samples. This formed the sample frame for the study, which was conducted in four phases. First, purposive sampling was used to select five crude oil exploration locations within the Degema oilfield in Obuama-Harry, Bille, Tombia, and Bukuma communities. Secondly, random sampling was conducted to select two soil samples from within 200 and 500 meters of each purposively selected community. Thirdly, the purposive sampling technique was used in the selection of two (2) samples from the Bille artisanal refining site. In the fourth and final phase, purposive sampling was used in the selection of 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. The six instruments used for data collection in this study included an Automated Global Positioning System (GPS), measuring tape, masking tape, a field notebook, a Ziploc bag, aluminum foil, and a hand auger. The researcher, assisted by a research assistant, conducted field observations and collected soil samples at six sampling points (four COES, 1 ARS, and Control) around the Degema oilfield, using automated GPS to determine locations. The GPS was used to determine the coordinates of six sampling points in the Degema oilfield, while a hand auger was used to collect triplicate soil samples at depths of 0-15 cm (topsoil) and 15-30 cm (subsoil) from five randomly selected oil-producing communities within the study area. After determining the coordinates, the hand auger was used to randomly collect top and sub-soil samples at various points. These samples were then combined into one representative sample from both 0-15 cm (topsoil) and 15-30 cm (sub-soil) depths across 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 heavy metals such as Lead (Pb), Cadmium (Cd), Chromium (Cr), Zinc (Zn), Iron (Fe), and Copper (Cu).

Laboratory Analysis of Soil Parameters: Upon arrival at the laboratory, soil samples were preserved in a refrigerator at 0 to 4 °C before analyzing selected heavy metals: Lead (Pb), Cadmium (Cd), Chromium (Cr), Zinc (Zn), Iron (Fe), and Copper (Cu). Analyses 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).

Data Analysis: Relevant Statistical Analytical tools like mean, charts, and graphs 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

Research Question 1: What are the heavy metal contents of the soil in the mangrove habitat in the crude oil exploration sites in the Degema oilfield?

Table 1: Mean Concentration of Heavy Metal Contents of the Mangrove Habitat in the Crude Oil Exploration Sites in Degema Oilfield

SP	**Pb (**mg/1)	**Cd (**mg/1)	**Cr (**mg/1)	**Zn (**mg/1)	**Fe (**mg/1)	**Cu (**mg/1)
	$\bar{x}$±SE	$\bar{x}$±SE	$\bar{x}$±SE	$\bar{x}$±SE	$\bar{x}$±SE	$\bar{x}$±SE
SP 1	0.07± 0.00	1.89±0.12	0.03±0.00	8.08±0.20	11.99±0.06	61.94±2.93
SP 2	0.02± 0.00	0.32±0.02	0.08±0.00	1.02±0.00	26.69±0.06	79.84±0.03
SP 3	2.69±0.05	0.00±0.00	0.88±0.00	1.26±0.00	19.79±0.09	36.86±0.10
SP 4	0.38± 0.01	2.80±0.04	0.03±0.00	1.15±0.04	23.56±0.06	86.54±0.11
Pooled $\bar{x}$±SE	**0.79±0.02**	**1.25±0.05**	**0.26±0.00**	**2.88±0.06**	**20.51±0.07**	**66.30±0.79**
Control	0.07±0.00	0.24±0.01	0.11±0.00	1.35±0.02	17.21±0.43	111.70±0.40
WHO (2017)	12.0-60.0	0.3-10.0	1.0-3.0	0.5-2.0	0.003	0.003
DPR (2011)	3.0	0.01	1.0	1.0	0.003	0.003

Source: Author's Computation, 2024

Legend: SP = Sampling Points, SP1 = Obuama-Harry Community, SP2 = Bille Community, SP3 = Tombia Community, and SP4 = Bukuma Community.

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Table 1 presents the mean concentrations of heavy metals in the mangrove habitat of the Degema oilfield's crude oil exploration sites. The analysis reveals variations in heavy metal levels among the sampling points. Lead (Pb) concentrations ranged from 0.02 mg/L in SP 2 to 2.69 mg/L in SP 3, with an overall mean of 0.79 mg/L, which is well below the World Health Organization (WHO) guideline of 12.0-60.0 mg/L. Cadmium (Cd) levels were significantly higher in SP 4 (2.80 mg/L) compared to other sites, with a pooled mean of 1.25 mg/L, exceeding WHO's limit of 0.3-10.0 mg/L. Chromium (Cr) levels remained low, with SP 3 having the highest concentration at 0.88 mg/L, and all sites collectively averaging 0.26 mg/L, which is within the WHO guideline of 1.0-3.0 mg/L. Zinc (Zn) and Iron (Fe) levels varied, with pooled averages of 2.88 mg/L for Zn and 20.51 mg/L for Fe. These values are within safe limits according to WHO standards. Copper (Cu) was notably high at SP 4 (86.54 mg/L), with a pooled mean of 66.30 mg/L, surpassing the DPR limit of 0.003 mg/L but below WHO's general concern level. Overall, the data suggests serious environmental implications, particularly concerning cadmium and copper concentrations, which could pose risks to both marine and human life. The graphical presentation of the heavy metals contents in the soil in Table 1 was contained in Figure 3 below.

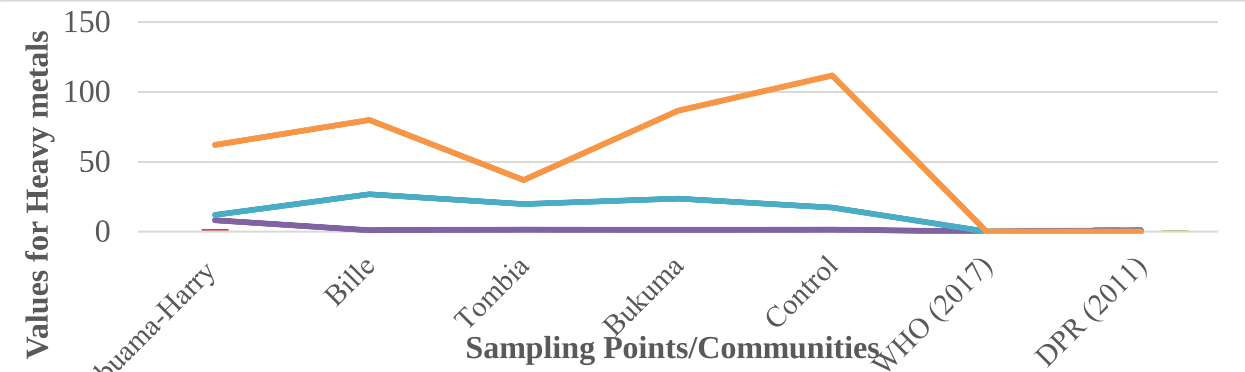

Figure 3: Line graph showing Mean Concentration of Heavy Metal Contents of the Mangrove Habitat in the Crude Oil Exploration Sites in Degema Oilfield

Figure 3 shows that copper (Cu) had the highest graphical values at the Control as well as other sampling points followed by iron (Fe) in all the sampling points/communities and Control. While the least graphical heavy metal property is lead (Pb) in all the sampling points in the soil in Degema Oilfield in Degema Local Government Area of Rivers State.

Research Question 2: What are the heavy metal contents of the soil in the mangrove habitat in the artisanal refining site in the Degema oilfield?

Table 2: Mean Concentration of Heavy Metal Contents of the Mangrove Habitat in the Artisanal Refining Site in Degema Oilfield

SP	**Pb** (mg/1)	**Cd** (mg/1)	**Cr** (mg/1)	**Zn** (mg/1)	**Fe** (mg/1)	**Cu** (mg/1)
	$\bar{x}$±SE	**$\bar{x}$±SE**	**$\bar{x}$±SE**	**$\bar{x}$±SE**	**$\bar{x}$±SE**	**$\bar{x}$±SE**
SP 5	0.49± 0.00	1.34±0.01	0.05±0.00	4.69±0.06	21.75±0.06	44.64±0.03
Control	0.07±0.00	0.24±0.01	0.11±0.00	1.35±0.02	17.21±0.43	111.70±0.40
WHO (2017)	12.0-60.0	0.3-10.0	1.0-3.0	0.5-2.0	0.003	0.003
DPR (2011)	3.0	0.01	1.0	1.0	0.003	0.003

Source: Author's Computation, 2024

Legend
SP5 = Bille Artisanal Refinery Site (Sampling Point 5)

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Table 2 presents the heavy metal concentrations in the mangrove habitat at the Bille Artisanal Refining Site (BARS) in Degema Oilfield. The results show elevated levels of lead (Pb) and cadmium (Cd) in SP 5 compared to the control site. Notably, Pb concentration (0.49 mg/L) in the artisanal refining site is significantly higher than the control (0.07 mg/L), and Cd (1.34 mg/L) exceeds the WHO (2017) limit of 0.3 mg/L. Iron (Fe) and copper (Cu) concentrations are also notably higher than safe limits, with Fe at 21.75 mg/L and Cu at 44.64 mg/L. These elevated metal levels highlight significant contamination at the artisanal refining site, posing potential ecological and health risks due to bioaccumulation in local fauna and flora.

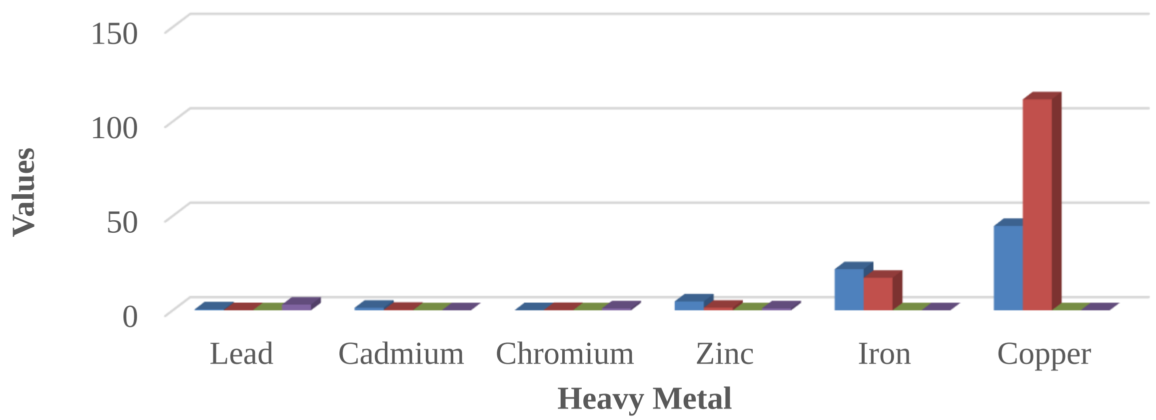

Figure 4: Mean Concentration of Heavy Metal Contents of the Mangrove Habitat in the Artisanal Refining Site in Degema Oilfield

Bille ARS, Control, WHO (2017), DPR (2011)

H_{01}: There is no significant difference in the heavy metal contents of the mangrove habitat in the crude oil exploration sites and artisanal refining site in the Degema oilfield

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

Parameters	Lead		Cadmium		Chromium		Zinc		Iron		Copper	
	F	p-value	F	p-value	F	p-value	F	p-value	F	p-value	F	p-value
Source of Variation	2346.384	0.000	484.877	0.000	45886.989	0.000	1112.250	0.000	761.974	0.000	533.159	0.000
Decision	S		S		S		S		S		S	

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

Table 2 shows the summary of the Analysis of Variance (ANOVA) on the difference in the heavy metal content of the mangrove habitat in the crude oil exploration sites and artisanal refining sites in the Degema oilfield in Degema Local Government Area Rivers State. It further shows that there is significant difference in the content of: Lead (F, 2346.384, p>.05), Cadmium (F, 484.877, p>.05), Chromium (F, 45886.989, p>.05), Zinc (F, 1112.250, p>.05), Iron (F, 761.974, p>.05), and Copper (F, 533.15, p>.05) of the mangrove habitat in the crude oil exploration sites and artisanal refining sites in the Degema oilfield. The null hypothesis was rejected. This indicated that the heavy metal content (such as lead, cadmium, chromium, zinc, iron, and copper) of the mangrove habitat significantly differs in the crude oil exploration sites and artisanal refining sites in the Degema oilfield in

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Degema Local Government Area Rivers State. This finding is similar to the different mean heavy metal contents of the mangrove habitat in Table 1 and Table 2 for the crude oil exploration sites and artisanal refining sites respectively in the Degema oilfield.

Discussion
The implications of the heavy metal concentrations presented in Table 1 are significant for environmental health and safety in the Degema oilfield. Elevated levels of cadmium and copper, particularly in Bukuma Community (SP 4) that exceed the recommended limits set by the World Health Organization (WHO) (2017), pose serious risks to marine ecosystems and could adversely affect the food chain. The presence of lead, although lower than WHO limits, remains a concern due to its cumulative effects on human health. Additionally, zinc and iron levels, while within safe ranges, highlight the need for ongoing monitoring. This finding is in agreement with Baker et al. (2021), and Ochoa et al. (2022) that prolonged exposure to high concentrations of copper (Cu) and zinc (Zn) accentuates contamination that disrupts local aquatic ecosystems affects biodiversity and food webs including various health issues, including neurological damage and kidney dysfunction.

Also, this finding is consistent with Deng et al. (2019) that the concentration of these heavy metals over time increases the pollution load of the inherent resources in an aquatic ecosystem (like the Jinjiang Estuary). This finding is consistent with the position of Onyena and Sam (2019) that heavy metals like Fe and Cu can seep into aquatic environments through human activities, especially oil exploration, leading to pollution, bioaccumulation, and adverse effects on biodiversity, humans, and the total environment. Against this backdrop, Igbani et al. (2024) suggested the integration of regular monitoring for adequate protection of the environment and its inherent resources that could be threatened by the spill, seepage, and bioaccumulation of the amount or quantity of Fe, Cu, and Pb that can affect water and fish species in an aquatic ecosystem.

The result from Table 2 reveals significant levels of heavy metals in the mangrove habitat near artisanal refining sites in Degema Oilfield, with concentrations exceeding control site levels. For instance, lead (Pb) at SP 5 is 0.49 mg/L, while cadmium (Cd) is elevated at 1.34 mg/L, both surpassing the WHO and DPR limits. This finding is in agreement with the finding by Udume and Olaiya (2021) that the heightened levels of cadmium and copper above (Cu) at 1.34 mg/L and 44.64 mg/L respectively suggest severe contamination, posing ecological and public health risks, as metals can bioaccumulate, affecting the food chain and human health. Also, the finding by Adekola et al. (2020) revealed that the elevated cadmium levels, can impair kidney function and cause other systemic health issues. The researchers align with these findings suggesting that artisanal refining activities could lead to toxic metal exposure and contamination that exacerbate environmental and human health risks likely to affect aquatic biodiversity and local communities dependent on these ecosystems.

This finding aligns with Otevia (2018) finding that the activity of crude oil exploration increases the concentration of heavy metals that in turn increase the level of toxicity and substances that eventually change the colouralization and appearance of the soil and waterbodies around Bille community in Degema Local Government Area of Rivers State. This finding agrees with Udume and Olaiya (2021) observation that artisanal refining leads to the concentration of noxious heavy metals that stir pollution that impacts mangroves, crucial for coastal ecosystems and biodiversity. The researchers align with the findings as artisanal refining could heighten the colouration and degradation of the soil around the Bille community (see Plates 1-3 below).


Plate 1: Polluted soil with toxic Plate 2: Polluted Waterbody with Plate 3: Polluted and depleted

Substance in Bille community. Warning on drinking, fishing and mangrove forest and habitat swimming in Bille community in Bille community.

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Table 3 indicates that the heavy metal content (such as lead, cadmium, chromium, zinc, iron, and copper) of the mangrove habitat significantly differs in the crude oil exploration sites and artisanal refining sites in the Degema oilfield in Degema Local Government Area Rivers State. This finding is consistent with the position of Geissen et al. (2015) that the operations in artisanal refineries could heighten the concentration of heavy metals, especially iron, cadmium, and lead in the aquatic and terrestrial ecosystems. This finding aligns with the studies (Nwankwo et al., 2022; Ogbogu et al., 2023) that heavy metal pollution adversely affects soil quality and vegetation health, posing risks to both human and ecosystem health. Also, this finding agrees with (Rafique et al., 2021; Al-Juboori & Abas, 2022) that elevated levels of heavy metals like cadmium and lead can inhibit plant development and reduce agricultural productivity, while also posing health risks to humans and wildlife through the food chain.

Conclusion

The study concludes that crude oil exploration and artisanal refining activities heightened the plausibility of the concentration of physicochemical properties such as Lead (Pb), Cadmium (Cd), Chromium (Cr), Zinc (Zn), Iron (Fe), and Copper (Cu) at different levels around the sampled communities in Degema oilfield. Thus, the presence of these chemicals overtime predisposes humans around the source communities in the Degema oilfield to reduced breathing, cardiovascular diseases, cancer, and other health-related diseases. Conclusively, the statistical analysis reveals a clear link between crude oil extraction activities and the concentration of harmful heavy metals in mangrove habitats, underscoring the need for targeted interventions to mitigate pollution and protect these vital ecosystems as well as safeguard human health.

Recommendations

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

1. The Federal and Rivers State Ministry of Environment in conjugation with Nigeria National Petroleum Company Limited (NNPCL) should implement effective regulatory enforcement, punitive actions, and/or operational license withdrawal as urgent interventions to mitigate oil companies' discharge of untreated effluents, and deliberate environmental pollution that impedes the goal of sustainable protection of both the environment and public health.
2. The National Oil Spill and Detection Response Agency (NOSDRA) in conjunction with the security operatives, and communities should adopt combatant and advocacy approaches to dismantle the growing artisanal refining sites that accentuate the release of untreated effluents and spill of chemicals containing varying levels of lead, cadmium, iron, and copper that can pollute the soil and eventually degrade the inherent mangrove habitats and plants.
3. The Nigeria Environmental Society should partner with the federal and state governments in designing a template for monitoring indigenous and multinational companies' conformity with standardized operational procedures that would mitigate the disposal of untreated effluents containing heavy metal pollutants that disrupt mangrove growth, stir biodiversity loss, contamination of food and water sources among other ecological consequences.

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