OPEN ACCESS
Scholars International Journal of Chemistry and Material Sciences
Abbreviated Key Title: Sch Int J Chem Mater Sci
ISSN 2616-8669 (Print) | ISSN 2617-6556 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: http://saudijournals.com

Original Research Article

Assessment of Heavy Metal Contamination in Water, Crab (*Scylla senrata*) and Sediments in Oil and Non-Oil Producing Communities in Akulga Local Government Area, Rivers State, Nigeria

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DOI: https://doi.org/10.36348/sijcms.2024.v07i09.001 | **Received:** 08.08.2024 | **Accepted:** 12.09.2024 | **Published:** 21.09.2024

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Abstract

This study aims to assess the concentrations of these heavy metals in water, crab, and sediment samples from oil-producing and non-oil-producing communities during low and high tides in Akulga Local Government Area, Rivers State. Samples were collected at both low and high tide regimes to assess the concentrations of heavy metals, including Fe, Pb, Ni, Mn, Zn, Cu, Cd, and Cr. The analyses were conducted using flame atomic absorption spectrophotometry. The results revealed that Kula sediments has significantly higher Fe levels (3844.80 mg/kg at low tide, 3663.30 mg/kg at high tide) compared to Abonnema (3622.10 mg/kg and 3117.50 mg/kg, respectively), with Mn and Cu also elevated. These concentrations exceed safe limits, indicating severe pollution. In crab samples, Kula showed higher Pb levels (38.28 mg/kg at low tide, 16.55 mg/kg at high tide) than Abonnema, exceeding WHO/FEPA safety limits and posing health risks. The elevated Mn and Cu levels also indicate bioaccumulation, raising concerns for the local ecosystem. Water samples showed minimal contamination, with most metal concentrations below detection limits and pH levels ranging from 5.55 to 6.49. Fe levels in Kula water remained within WHO permissible limits. Also, the analysis of variance findings on samples collected at low and high tides from Abonnema (ABO) and Kula (KUL) communities indicate significant differences ($p < 0.05$) in heavy metal concentrations in sediment, crab, and water samples. In conclusion, the results reveal significant heavy metal pollution in Kula, especially in sediment and crab samples, posing potential health risks to local communities. There is therefore the need for continuous environmental monitoring and remediation to mitigate the adverse effects of industrial activities in the study area.

Keywords: Heavy metals, oil pollution, Kula, Abonnema, *Scylla senrata*, sediment, water.

INTRODUCTION

Heavy metal contamination in aquatic environments is a critical environmental issue, particularly in regions affected by industrial activities such as oil exploration and production. These activities can result in the discharge of hazardous substances, including heavy metals, into the environment, leading to significant ecological and public health challenges [1]. The Niger Delta region of Nigeria, known for its extensive oil and gas operations, has been identified as a hotspot for environmental degradation, including heavy metal pollution in water bodies, sediments, and biota [2].

Among various aquatic organisms, fish have been recognized as significant indicators of environmental contamination and bioaccumulation of heavy metals, as they are at the top of aquatic food chains and can accumulate these toxic substances over time. Fish accumulate toxic chemicals such as heavy metals directly from water and diet, and contaminant residues may ultimately reach concentrations of hundreds or thousands of times above those measured in the water, sediment and food [3]. Aquatic ecosystems are particularly vulnerable to heavy metal pollution, and the continual rise of these metals in the environment, largely due to human activities like accidental chemical waste spills, industrial and sewage discharge, agricultural runoff, domestic wastewater, and fuel leakage from fishing boats, has become a cause for concern [4].

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and manganese (Mn) are of particular concern due to their toxicity, persistence in the environment, and potential to bioaccumulate in living organisms. These metals can cause severe health issues, including neurological disorders, renal dysfunction, and increased risk of cancer, even at low concentrations [5, 6]. In aquatic ecosystems, heavy metals can accumulate in sediments and be taken up by aquatic organisms, eventually entering the human food chain through the consumption of contaminated water and seafood.

This study aims to assess the concentrations of these heavy metals in water, crab, and sediment samples from oil-producing and non-oil-producing communities during low and high tides in Akulga Local Government Area, Rivers State. By comparing data from Kula (an oil-producing community) and Abonnema (a non-oil-producing community), the study seeks to highlight the impact of oil production on environmental contamination.

MATERIALS AND METHOD

Description of Study Area

The study area encompasses Kula and Abonnema in the Akuku-Toru Local Government Area (Akulga) of Rivers State, Nigeria (Fig. 1). Akulga comprises several communities namely; Abonnema, which is the head quarter, Idama, Kula, Obonoma, Abissa, Orusangama, Elem Sangama and Soku. Akulga is an economically significant region covering approximately 1,443 km² with a population of about 156,006 people (Fed. Rep. Nig. Gazette, 2015; Census, 2006).

The study area is situated between latitudes 04°44'09.6" N and 04°20'37.4" N, and longitudes 006°46'28.8" E and 006°38'39.9" E, within the Niger Delta region along the Sombrero River. It features fibrous clay mud, indicative of high compressibility and consolidation [7]. The region experiences a tropical monsoon climate with frequent rainfall throughout the year, except for December, January, and February, when rainfall is less consistent [7]. Surface river water in Akulga primarily has a Sodium Chloride (NaCl) composition, which exhibits slight salinity during the dry season [8]. This saline water can be processed into table salt through fractional recrystallization [7].

The focus on Kula and Abonnema is due to their contrasting environmental conditions. Kula, an oil-producing community, is notably affected by oil and gas exploration activities, while Abonnema, a non-oil-producing community, serves as a reference for comparison. The presence of major oil and gas plants in Kula has led to increased exploration and exploitation, impacting the local environment.

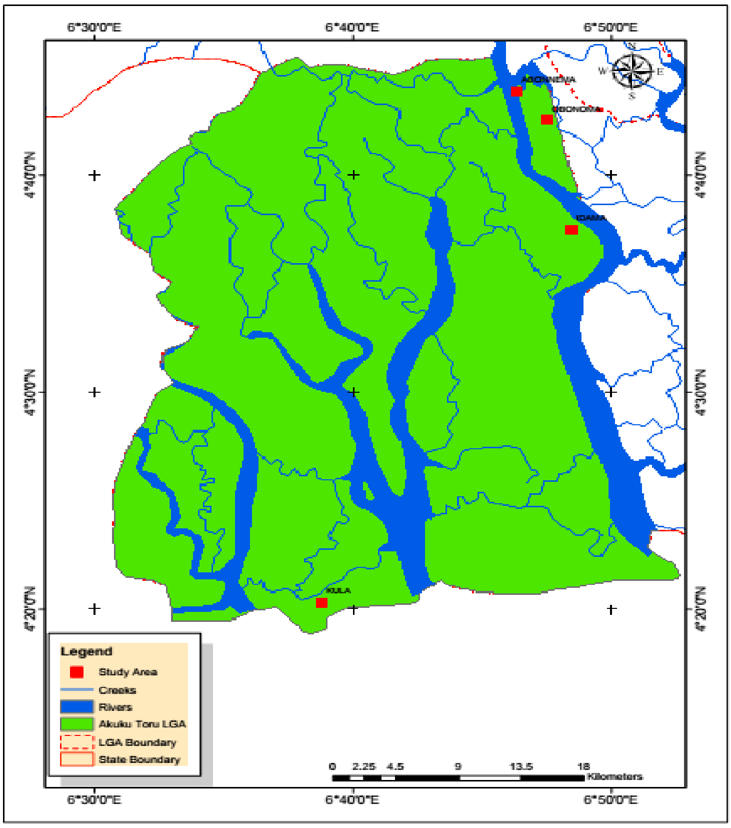

Figure 1: Map of Study Area showing sampling points and Rivers

Sample Collection and Preparation

Water, Crab (*Scylla senrata*) and Sediment samples from Kula (oil producing community) and Abonnema (non-oil producing community) creeks at low and high tide regimes were sampled. Each sample was collected 5 times. Water samples were collected in polythene bottles, sediment and crab samples were collected in polythene bags. Sediment and crab samples were oven-dried to constant weight, ground, and sieved. For digestion, 1 g of each dried sediment and crab sample was treated with 5 mL of 65% nitric acid (HNO_3), gently boiled at 90°C for 1–2 hours, then further digested with an additional 2.5 mL of 65% HNO_3 until clear. The digested samples were filtered. Water samples were filtered without digestion.

Determination of Heavy Metal Levels in Water, Sediment and Crab

The concentrations of heavy metals (Pb, Cd, Cr, Fe, Ni, Mn, Cu, and Zn) in the filtered water and digested sediment and crab samples were determined using a flame atomic absorption spectrophotometer (FAAS). Prior to analysis, the instrument was calibrated with a calibration blank and a series of five working standard solutions for each metal of interest. This calibration process ensured accuracy and reliability in the measurement of heavy metal concentrations. The digested samples were then analyzed for their heavy metal content, following the manufacturer's instructions and standard analytical procedures. Quality control measures, including the use of blanks, standards, and duplicate samples, were employed to ensure the precision and accuracy of the results.

Statistical Analysis

Data analysis was carried out using SPSS version 21.0. The significance of differences in metal concentrations between samples from non-oil-producing (Abonnema) and oil-producing (Kula) communities, as well as between high and low tide regimes, was assessed using Analysis of Variance (ANOVA) at a significance level of $p<0.05$. Results were presented in tables to illustrate the significant differences in heavy metal contamination between the various sample sites and tidal conditions.

RESULTS AND DISCUSSION

The concentrations of heavy metals in sediments, water and crab samples are shown in Table 1. The analysis of variance findings on samples from non-oil and oil producing communities in low and high tides are tabulated in Table 2 and 3.

Table 1: Results of the analyses of sediment, crab, water samples at low and high tide

Sample ID	pH	Fe (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Cd (mg/kg)	Cr (mg/kg)
LOW TIDE									
SEDIMENT									
ABO (NOPC)	2.1	3622.10	<0.001	1.55	11.61	6.23	2.12	0.15	1.94
KUL (OPC)	0.58	3844.80	<0.001	2.42	14.97	6.92	4.05	0.22	2.10
CRAB									
ABO (NOPC)	8.37	125.6	8.3	5.43	65.27	11.68	25.69	1.25	0.21
KUL (OPC)	8.49	146.8	38.28	6.45	71.43	12.66	27.95	1.71	0.28
WATER									
ABO (NOPC)	5.55	0.017	<0.001	<0.001	0.226	0.014	<0.001	<0.001	<0.001
KUL (OPC)	6.22	0.16	<0.001	<0.001	0.344	0.022	<0.001	0.014	<0.001
HIGH TIDE									
SEDIMENT									
ABO (NOPC)	2.14	3117.50	<0.001	0.73	13.4	5.37	1.54	1.32	1.53
KUL (OPC)	0.65	3663.30	<0.001	2.98	21.62	13.3	3.99	<0.001	2.45
CRAB									
ABO (NOPC)	8.57	94.7	16.04	3.62	42.79	13.48	18.5	1.29	<0.001
KUL (OPC)	8.85	111.9	16.55	6.26	45.27	13.98	26.23	2.00	<0.001
WATER									
ABO (NOPC)	5.73	<0.001	<0.001	<0.001	0.021	0.005	<0.001	<0.001	<0.001
KUL (OPC)	6.49	0.033	<0.001	<0.001	0.004	0.016	<0.001	<0.001	<0.001

Key: NOPC: Non-oil producing community. OPC: Oil producing community. ABO =ABONNEMA; KUL = KULA

Table 2: SPSS results of data obtained from the analyses of samples from non-oil and oil producing communities

HIGH TIDE									
Concentration in mg/kg									
Sample ID	**pH**	**Fe**	**Pb**	**Ni**	**Mn**	**Zn**	**Cu**	**Cd**	**Cr**
SEDIMENT									
ABO (NOPC	*	*	<0.001	*	*	*	*	*	*
KUL (OPC)			<0.001						
CRAB									
ABO (NOPC)	*	*	*	*	*	*	*	*	<0.001
KUL (OPC)									<0.001
WATER									
ABO (NOPC)	*	*	<0.001	<0.001	*	*	<0.001	<0.001	<0.001
KUL (OPC)			<0.001	<0.001			<0.001	<0.001	<0.001
LOW TIDE									
SEDIMENT									
ABO (NOPC)	*	*	<0.001	*	*	*	*	*	*
KUL (OPC)			<0.001						
CRAB									
ABO (NOPC)	*	*	*	*	*	*	*	*	*
KUL (OPC)									
WATER									
ABO (NOPC)	*	*	<0.001	<0.001	*	*	<0.001	*	<0.001
KUL (OPC)			<0.001	<0.001			<0.001		<0.001

Table 3: SPSS results of data obtained from the analyses of samples at low and high tide

Concentration in mg/kg									
Sample ID	**pH**	**Fe**	**Pb**	**Ni**	**Mn**	**Zn**	**Cu**	**Cd**	**Cr**
SEDIMENT									
ABO (LOW)	*	*	<0.001	*	*	*	*	*	*
ABO (HIGH)			<0.001						
KUL (LOW)	*	*	<0.001	*	*	*	*	*	*
KUL (HIGH)			<0.001						
CRAB									
ABO (LOW)	*	*	*	*	*	*	*	*	*
ABO (HIGH)									
KUL (LOW)	*	*	*	*	*	*	*	*	*
KUL (HIGH)									
WATER									
ABO (LOW)	*	*	<0.001	<0.001	*	*	<0.001	<0.001	<0.001
ABO (HIGH)			<0.001	<0.001			<0.001	<0.001	<0.001
KUL (LOW)	*	*	<0.001	<0.001	*	*	<0.001	*	<0.001
KUL (HIGH)			<0.001	<0.001			<0.001		<0.001

pH Level Measurements

The pH levels of sediment, crab, and water samples were compared between low and high tides in both oil-producing (Kula) and non-oil-producing (Abonnema) communities, as illustrated in figure 2 and Table 1.

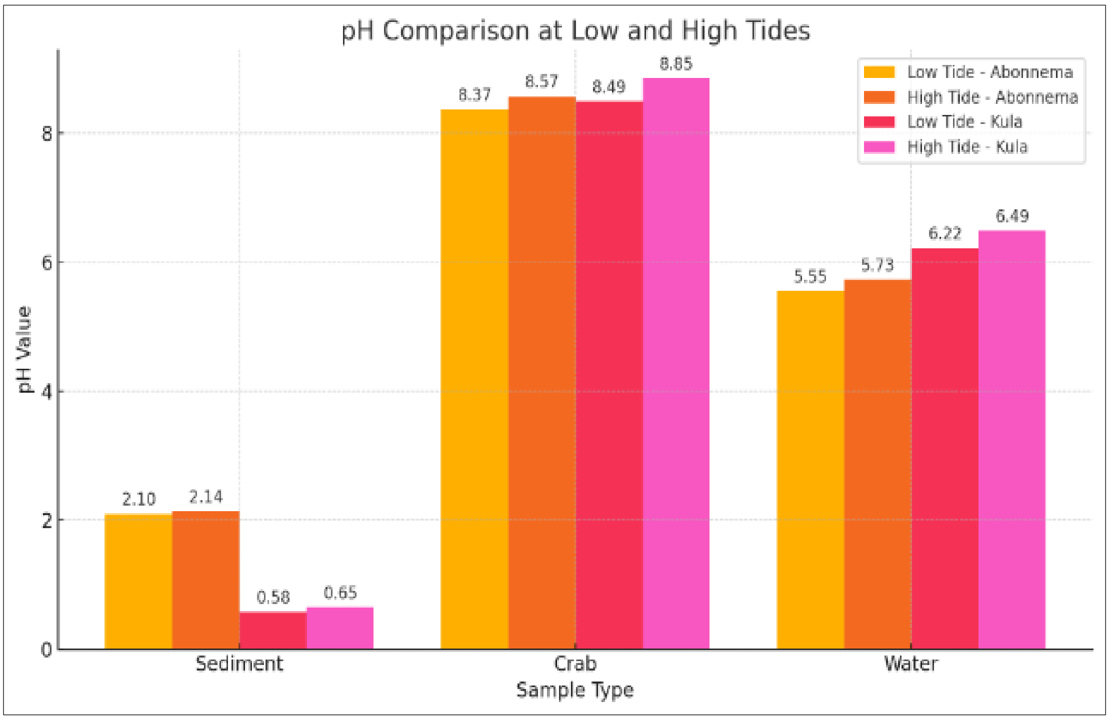

Figure 2: pH values for sediment, crab, and water samples at low and high tides in both Abonnema (non-oil-producing community) and Kula (oil-producing community)

In the sediment samples, pH values were consistently acidic, with Kula exhibiting more extreme acidity than Abonnema. At low tide, sediment pH in Abonnema was 2.1, while in Kula, it was significantly lower at 0.58. This difference suggests that oil production activities in Kula may contribute to greater acidity in the sediment. At high tide, there was a slight increase in pH in both communities, with Abonnema rising to 2.14 and Kula to 0.65. The small increase during high tide could be due to the dilution of acidic substances as tidal waters mix with the sediment, slightly reducing the overall acidity.

Crab tissue pH remained alkaline across both communities and tidal conditions, indicating a stable internal environment that buffers against external pH fluctuations. At low tide, the pH in crab tissue was 8.37 in Abonnema and 8.49 in Kula. At high tide, these values increased slightly to 8.57 in Abonnema and 8.85 in Kula. The consistent alkalinity, as seen in the chart, suggests that crabs have adaptive mechanisms to maintain their internal pH despite the surrounding acidic conditions, possibly through physiological buffering systems.

Water samples, as depicted in the graph, exhibited near-neutral pH levels, with Kula consistently showing slightly higher values than Abonnema. At low tide, water pH in Abonnema was 5.55, and in Kula, it was 6.22. At high tide, both locations showed a minor increase in pH, with Abonnema rising to 5.73 and Kula to 6.49. The higher pH values in Kula's water compared to Abonnema's suggest that local environmental factors, such as oil production, may influence the water chemistry, leading to less acidic conditions. The slight increase in pH at high tide might be due to the mixing of different water masses, which can dilute acidic inputs.

The pH results highlight the significant impact of oil production on sediment acidity and the adaptive responses of local biota, and the influence of tidal changes on water pH in these communities.

Concentrations of Heavy Metals in Sediment Samples at Low and High Tide

The analysis of sediment samples revealed significant differences in heavy metal concentrations between the oil-producing community (KUL) and the non-oil-producing community (ABO). At low tide, Kula recorded 3844.80 mg/kg, while Abonnema had 3622.10 mg/kg. At high tide, these values slightly decreased to 3663.30 mg/kg in Kula and 3117.50 mg/kg in Abonnema. The concentrations of iron (Fe) in the analyzed sediment samples are far above the WHO [9] and FEPA [10] standard of 3.5 mg/kg. This elevated level of Fe in KUL sediments can likely be attributed to the industrial activities associated with oil exploration and refining, which often release iron-rich particulates into the surrounding environment. The slight decrease at high tide might be due to the dilution effects of incoming tidal waters.

Lead (Pb) levels were below detectable limits in both communities' sediments, indicating minimal contamination by this heavy metal. The absence of significant lead concentrations suggests that neither area is currently experiencing lead pollution, which could be a positive sign of minimal industrial lead input or effective environmental management in these regions.

Nickel (Ni) concentrations were higher in Kula than in Abonnema. At low tide, Kula recorded 2.42 mg/kg, and Abonnema 1.55 mg/kg. These values increased slightly at high tide to 2.98 mg/kg in Kula, while Abonnema saw a decrease to 0.73 mg/kg. The presence of nickel in higher concentrations in Kula could be due to the contribution of oil production activities, as nickel is often associated with crude oil and can be released into the environment through spills and other industrial processes.

Manganese concentrations were also higher in Kula compared to Abonnema. At low tide, Kula had 14.97 mg/kg, while Abonnema had 11.61 mg/kg. At high tide, Kula's manganese concentration increased significantly to 21.62 mg/kg, whereas Abonnema's increased slightly to 13.4 mg/kg. The concentration of manganese was below the limit set by WHO [9] and FEPA [10] of 17.453 mg/kg (Table 4). Manganese is known to accumulate in sediments, particularly in areas with industrial activity, and its elevated levels in Kula could be attributed to oil production. Zinc levels were slightly higher in Kula than in Abonnema, with 6.92 mg/kg and 6.23 mg/kg, respectively, at low tide. At high tide, Kula's zinc concentration increased to 13.3 mg/kg, while Abonnema's decreased to 5.37 mg/kg. The results obtained were below the WHO [9] and FEPA [10] recommended limit (16.063 mg/kg) of Zn in sediment (Table 4). The increase in zinc levels at high tide in Kula could be due to the resuspension of zinc from sediment as a result of tidal action, which is a common phenomenon in coastal environments.

Copper concentrations were also elevated in Kula compared to Abonnema, with Kula recording 4.05 mg/kg at low tide and 3.99 mg/kg at high tide, while Abonnema had 2.12 mg/kg and 1.54 mg/kg, respectively. These measurements greatly surpass the WHO [9] and FEPA [10] standard of 0.669 mg/kg. Copper is often found in association with oil extraction activities, and its higher levels in Kula support this association. Cadmium and chromium levels were low across both communities, with Kula showing slightly higher values at both tides. At low tide, cadmium was 0.22 mg/kg in Kula and 0.15 mg/kg in Abonnema which are below the WHO [9] and FEPA [10] standard of 2.630 mg/kg (Table 2), while chromium was 2.10 mg/kg in Kula and 1.94 mg/kg in Abonnema. At high tide, cadmium decreased to undetectable levels in Kula and increased slightly to 1.32 mg/kg in Abonnema. Chromium showed a slight increase in Kula to 2.45 mg/kg and a decrease in Abonnema to 1.53 mg/kg. The generally low levels of these metals suggest limited contamination, but the higher concentrations in Kula point to the influence of industrial activities.

The consistently higher concentrations of heavy metals in KUL sediments during both low and high tides suggest a continuous influx of contaminants from oil production activities, which accumulate in the sediments over time.

Concentrations of Heavy Metals in Crab Samples at Low and High Tide

The levels of heavy metals in crab obtained from Kula and Abonnema were evaluated and the results are presented in Tables 1. From the result, Iron concentrations in crabs were higher in Kula (146.8 mg/kg) than in Abonnema (125.6 mg/kg) at low tide. At high tide, these levels decreased to 111.9 mg/kg in Kula and 94.7 mg/kg in Abonnema. The results obtained from the crab samples were above the WHO [9] and FEPA [10] (0.5 mg/kg) recommended limit of Fe in food (Table 4). However, it's important to note that iron is a common element and essential nutrient. Increased level of iron may cause conjunctivitis, choroiditis, and retinitis if it contacts and remains in the tissues [11]. While these levels may be elevated, they are unlikely to pose a direct health concern. The higher iron levels in crabs from Kula could be a result of bioaccumulation due to the elevated iron levels in the sediment. Lead levels in crab tissue were significantly higher in Kula, with 38.28 mg/kg at low tide and 16.55 mg/kg at high tide, compared to Abonnema, which had 8.3 mg/kg at low tide and 16.04 mg/kg at high tide. The results obtained were above the WHO/FEPA (2.0 mg/kg) recommended limit of Pb in food. The elevated lead levels in Kula may be due to increased exposure to lead contaminants, possibly from industrial sources associated with oil production. Nickel concentrations in crabs were higher in Kula (6.45 mg/kg at low tide and 6.26 mg/kg at high tide) than in Abonnema (5.43 mg/kg at low tide and 3.62 mg/kg at high tide). Nickel (Ni) concentrations in the crab from both communities are well above the WHO [9] and FEPA [10] standard of 2.0 mg/kg (Table 4). The bioaccumulation of nickel in crabs from Kula suggests a greater environmental presence of this metal, likely from oil-related activities. Manganese, zinc, and copper levels were all higher in crabs from Kula than from Abonnema, both at low and high tides. This pattern is consistent with the elevated levels of these metals in the sediment and indicates bioaccumulation in crabs. At low tide, manganese was 71.43 mg/kg in Kula and 65.27 mg/kg in Abonnema; zinc was 12.66 mg/kg in Kula and 11.68 mg/kg in Abonnema; and copper was 27.95 mg/kg in Kula and 25.69 mg/kg in Abonnema (Table 1). These values decreased slightly at high tide but remained higher in Kula. The concentrations of Mn, Zn and Cu in the crab samples were beyond the permissible limits set by WHO [9] and FEPA [10] and this raise concern regarding potential health risks.

The consistently high levels of these metals in KUL crabs during both low and high tides reinforce the notion that oil production activities are a major source of metal contamination, leading to higher bioaccumulation rates and posing significant ecological and public health risks.

Concentrations of Heavy Metals in Water Samples at Low and High Tide

Water samples analyzed during low tide revealed low concentrations of heavy metals, with some metals being below detectable levels in both KUL and ABO. However, certain differences were noted. Iron concentrations in water were very low, with Kula showing slightly higher levels (0.16 mg/kg at low tide and 0.033 mg/kg at high tide) compared to Abonnema (0.017 mg/kg at low tide and undetectable at high tide). These levels significantly fall below the WHO [9] and FEPA [10] standard of 0.300 mg/L (Table 4). The low iron levels in water reflect the natural separation of metals in the water column, as most iron tends to precipitate and settle in the sediment. The concentrations of lead, nickel, manganese, zinc, copper, cadmium, and chromium in water were either below detectable limits or very low, with no significant differences between the two communities. This indicates minimal contamination of these metals in the water column, possibly due to their preference for sediment binding over remaining dissolved in water. From the results the lead, nickel, manganese, zinc, copper, cadmium, and chromium levels detected were generally within WHO guidelines for drinking water (Table 4).

Analysis of Variance of samples From Non-oil and oil Producing Communities

The results shown in Table 2 indicate significant differences in heavy metal concentrations in sediment, crab, and water samples from non-oil-producing (Abonnema) and oil-producing (Kula) communities during high and low tides. In sediments, Pb was significantly present (<0.001 mg/kg) across both sites and tides, indicating persistent contamination likely associated with industrial activities. In crabs, Cr was significantly detected (<0.001 mg/kg) in both communities during high tide, reflecting potential bioaccumulation and food web impacts. Water samples from both communities showed significant levels of Pb, Ni, Cd, and Cr (<0.001 mg/kg), indicating ongoing exposure to pollution sources. pH levels varied but did not significantly influence metal concentrations. The findings emphasize the environmental and health risks posed by heavy metal contamination, particularly in oil-producing regions.

Analysis of Variance of Data Obtained from the Analyses of Samples at Low and High Tide

The results shown in Table 3 highlight the concentrations of heavy metals in sediment, crab, and water samples collected at low and high tides from Abonnema (ABO) and Kula (KUL) communities. The SPSS analysis indicates significant variations in heavy metal levels across different tidal conditions, with statistical significance set at $p<0.05$.

In sediment samples, Pb was consistently detected at significant levels (<0.001 mg/kg) during both low and high tides in both communities, suggesting persistent lead contamination that is not significantly affected by tidal changes. This persistent presence of Pb in sediment points to continuous contamination sources, likely from anthropogenic activities, including industrial discharge or oil production in Kula. Crab samples did not show significant levels of heavy metals accumulation at either low or high tides in both communities, suggesting limited bioavailability or uptake during the sampling period. Water samples revealed significant concentrations of Pb, Ni, Cd, and Cr (<0.001 mg/kg) across both communities and tidal conditions, indicating ongoing contamination regardless of tidal influence. pH measurements varied but did not show significant differences that correlated directly with metal concentrations, suggesting that metal pollution in these environments is primarily influenced by external contamination sources rather than pH-driven solubility changes.

Table 4: International guidelines for heavy metals in fish, sediment and water

	Fish	Sediments	Water
Heavy Metals	**Maximum Limit WHO/FEPA (mg/kg)**	**Maximum Limit WHO/FEPA (mg/kg)**	**Maximum Limit WHO/FEPA (mg/L)**
Zn	30	16.063	3.000
Cu	3.0	0.669	1.000
Mn	0.5	17.453	0.050
Fe	0.5	3.5	0.300
Pb	2.0	2.063	0.010
Cd	0.5	2.630	0.003
Ni	2.0	-	-

CONCLUSION

The study indicates that heavy metal concentrations are higher in sediment and crab samples from the oil-producing community compared to the non-oil-producing community. This suggests that oil production activities significantly impact environmental pollution. The results highlight the need for continuous monitoring and management to mitigate the effects of heavy metal contamination on the environment and public health.

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