

**Distribution of Heavy Metals and Macrobenthic Invertebrates in Sediment of the Escravos
Estuary, Nigeria**

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Abstract

This study evaluated the distribution of heavy metals and the macrobenthic invertebrates in sediments at an estuary impacted by wastewater effluents from petroleum and gas operations in the Niger Delta region of Nigeria. Sediment samples were collected monthly for six months from five locations by standard methods and analysed for pH, EC, TOC, nitrate, phosphate, sulphate, Cd, Pb, Zn, Cu, Fe, TPH and macrobenthic invertebrates. The distribution of heavy metals in sediments was in the order of $Fe > Zn > Pb > Cu > Cd$. Mean Cd (7.31 ± 12.76) and TPH (66.81 ± 32.64) were above the permissible limits of 0.8 mg/kg and 50.0 mg/kg respectively. A total of 65 individuals belonging to 7 species, 7 genera, 7 families and 3 phyla were recorded. Molluscs accounted for 60% of the macrobenthic invertebrates with decreased species diversity and dominance across the sampled sites. Geo-accumulation index and contamination factor showed moderate to high contamination for Cd and Pb, while ecological and pollution index reveal severe risk of ecological degradation due to increased metal contamination of the Escravos Estuary. This study highlights the impact of petrochemical operations on the ecology of the Escravos Estuary. There is a need for the regular monitoring of wastewater effluents from petroleum and gas operations into the estuary to prevent ecosystem collapse in the region.

Keywords: ecological risk assessment, heavy metals, anthropogenic stressors, pollution, benthic organisms.

1.0 Introduction

Coastal areas in developing countries face anthropogenic pressures due to increased human activities and industrial effluents from commercial centres. Contaminants from human activities along the coast enter coastal ecosystems with cascade effects on aquatic organisms and communities within the coastal region. Given widespread atmospheric deposition in form of soot, unregulated dumping of wastes, agricultural runoff, crude oil spillages, industrial effluents, ballast water and shipping wastes, environmental quality evaluation has become necessary in the marine, brackish and freshwater ecosystems. There has been a great deal of environmental pollution due to these factors (Ayotunde and Bariweni, 2018; Ebuete and Bariweni, 2019; Nworu *et al.*, 2019). The Lancet Commission on Pollution and Health reported that in 2015 air, soil, and water pollution caused 16% global deaths. Developing countries recorded over 90% of such deaths, particularly in children (Landrigan *et al.*, 2017). Surface water and sediment quality are vital in aquatic organisms' distribution, abundance, and diversity. However, sediments are a better gauge of contaminant levels in aquatic ecosystems than surface water (Oderinlewo and Bariweni, 2020). The distribution and production of fish and other aquatic species can be directly or indirectly impacted by the physical and chemical features of sediments, making them a significant variable in coastal ecosystem (Ekperusi *et al.*, 2022; Onyena, 2019). A large proportion of contaminants entering coastal waters settles at the bottom sediments, thereby posing a threat to the ecology and diversity of benthic organisms in such ecosystems. Contaminants reaching the bottom substratum in coastal ecosystems are further degraded by aerobic and anaerobic microbes to either harmless or toxic components causing anoxic conditions and the bioaccumulation of contaminants in aquatic biota with possible transfer through the food chain (Ekperusi *et al.*, 2022; Onyena, 2019).

Benthic macroinvertebrates play vital role as a connection between energy inputs and transmission to higher trophic levels (Nkwoji *et al.*, 2020). In addition to physicochemical characteristics, macroinvertebrates provide crucial information to enhance understanding of environmental fluctuations (Ikomi *et al.*, 2005) as they are sensitive and can detect xenobiotics affecting an ecosystem (Herman and Nejadhashemi, 2015). Furthermore, beside their prevalence and sessile nature, macroinvertebrates incorporate environmental circumstances and provide a great representation of an ecosystem (Onyena, 2019; Nkwoji and Awodeyi, 2018; Nkwoji *et al.*, 2016).

There is a concern that chemical contaminants including heavy metals mainly from petroleum and gas operations are impacting biota in the estuarine creeks and the entire Escravos coastal region (Nworu *et al.*, 2019). It has been reported that municipal waste discharges such as sewage, abattoir waste, refuse dumps and oil spills, from human activities along coastal communities disturb surface water and sediment quality of the Niger Delta region (Bekeowei and Bariweni, 2021; Davies and Ekperusi, 2021; Ayotunde and Bariweni, 2018; Onyena, 2019; Nkwoji *et al.*, 2020). These activities lead to water and sediment contamination, ecosystem degradation, biodiversity loss, and other socio-economic problems

(Zhang *et al.*, 2019). This study investigates the distribution of heavy metals and macrobenthic organisms in sediments of the Escravos Estuary in the Niger Delta region of Nigeria.

2.0 Materials and Methods

2.1 Study Area

Escravos Estuary is situated in Warri South-West Local Government Area of Delta State, Nigeria (Figure 1). The estuary is a distributary of the Niger River in the western Niger Delta in southern Nigeria. It flows westward and passes through areas characterized by mangrove swamps and coastal sand ridges before entering the Bight of Benin within the Gulf of Guinea (Britannica, 1998). The estuary is flanked on both sides by several island communities and host the Escravos Terminal, one of the major oil and gas processing zone in Nigeria. The main economic activities in the area are oil and gas exploration and production, artisanal refining of crude oil, subsistent and artisanal fishing. The estuary is also the main shipping route to Warri Port and serve as inland waterway transportation for goods and services within coastal communities and the mainland in Warri metropolis. The estuary has a large flood plain that is impacted by tides and dominated by mangrove (*Rhizophora racemosa* and *Rhizophora mangle*) ecosystems. The region experiences two seasons: the wet (April to November) and dry season (December to March). The relative humidity is about 80% and the mean temperature ranges from 26°C to 33°C with annual rainfall of over 3000mm. The heavy rains experienced in the area results in high runoff which can influence the water and sediment quality (Ayotunde and Bariweni, 2018).

Five sample sites namely Izalagha (Station 1, 751184.05E, 619623.98N), Oporoza (Station 2, 753007.78E, 619463.31N), Kunukunuma (Station 3, 758283.53E, 617823.05N), Dockyard (Station 4, 762562.36E, 619442.71N) and Okerenkoko (Station 5, 764489.12E, 621169.99N), were chosen along the coastline considering their proximity to anthropogenic stressors such as human settlement, artisanal refining of crude oil and oil and gas production and processing zone. These human activities in the area makes the estuary a receptacle for untreated and poorly treated domestic and industrial wastewater effluents.

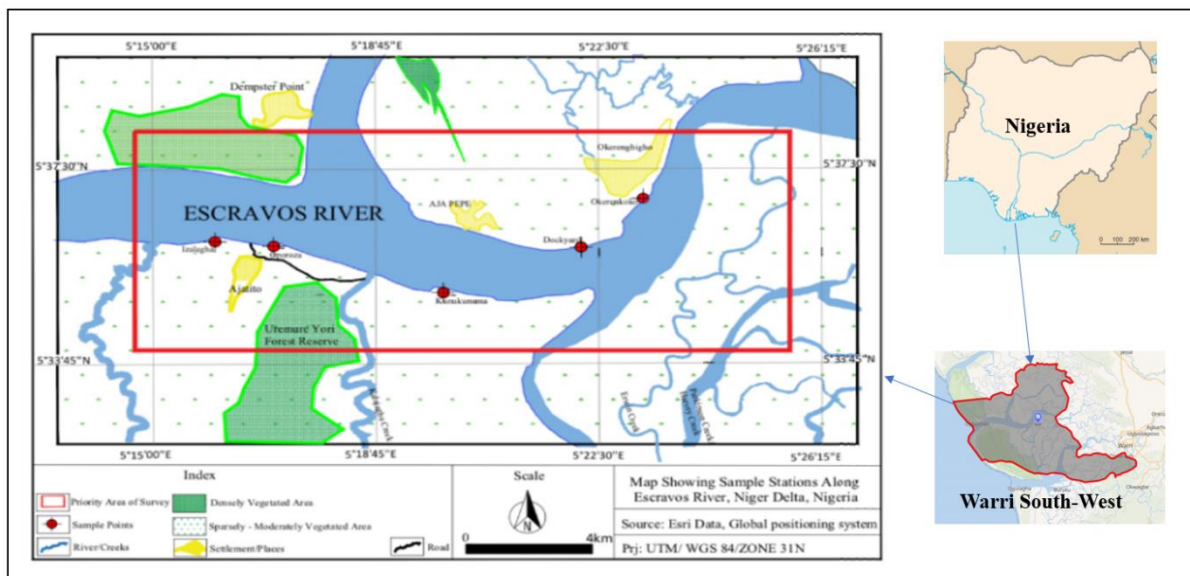


Figure 1. Map of the study area with sampled stations highlighted in dot along the Escravos Estuary, Nigeria

2.2 Sediment Sample

Sediment samples were collected aboard a speedboat with a Van Veen grab from five sampling stations along the estuary (Figure 1) from December 2021 to May 2022 between 08:00 and 10:30 hours. Three hauls of sediments were randomly collected into a bucket and homogeneously mixed to obtain a composite sample. All sediments samples were collected with replicates. The mixed samples were wrapped in aluminium foil, and kept in ice box before they were transported to the laboratory for analysis.

2.3 Benthic Invertebrate Sample

Sediments for macroinvertebrate species were sieved *in-situ* using a 0.5mm mesh and benthic samples were obtained. Sieved benthic samples were preserved with 10% formaldehyde for further analysis. At the laboratory, samples were cleaned to remove debris, sorted and fixed in 70% alcohol. The benthic organisms were sorted with the aid of a digital microscope and identified using taxonomy keys (Easton *et al.*, 2012; Mike *et al.*, 2005).

2.4 Laboratory Analysis

The pH and electrical conductivity of sediments were measured in the laboratory with Hanna pH and Conductivity Metre (H19828) after calibration. Heavy metals in sediment samples were determined using Atomic Absorption Spectrophotometry (AAS, model AA500), according to APHA 3011A method (APHA, 2018). Five grams of air-dried sediment sample was digested using 2 ml of nitric acid (HNO₃) and 10 ml of hydrochloric acid (aqua-regia mixture). The extract was filtered through a

Whatman filter paper, into a 50 ml volumetric flask. The sample was diluted and reconstituted using distilled water. Heavy metal concentration was determined by the direct aspiration of the sample into the flame cell of the instrument. Total petroleum hydrocarbon (TPH) was determined using Gas Chromatography with Flame Ionization Detector (GC-FID) following APHA 5520F method (APHA, 2017). One gram of air-dried sediment sample was weighed into a glass extraction vessel. About 10 ml of dichloromethane was mixed with the sediment. The extract was filtered through a chromatographic column packed with glass wool, slurry of activated silica and anhydrous sodium sulphate. The eluent was collected into sample vials and injected through a hypodermic syringe into the gas chromatograph to obtain the aliphatic fractions (TPH) which automatically get detected on the flame ionization detector as signals are collected depending on the composition of the vapour and the generated chromatogram of result is read as mg/kg TPH. All reagents and blanks used for the determination of heavy metals and hydrocarbons were analytical grade.

2.5 Data Analysis

Descriptive statistics such as mean and standard deviation were obtained and one-way analysis of variance (ANOVA) was used to test for the level of significance at 0.05 probability levels using Statistical Package for Social Sciences (SPSS 21). Pearson correlation was used to test the relationship between the physicochemical parameters and macrobenthic fauna. Palaeontological software (PAST) ver. 2 was used for the computation of biological indices. Sediment contamination, pollution and potential ecological risk assessment from sediment were assessed by:

- i) *Potential Ecological Risk Index (PERI)*: The potential risks of heavy metals to the ecosystem integrity was evaluated using PERI (Hakanson, 1980) and calculated with the formula:

$$PERI = \sum_{i=1}^x E_r^i \quad \text{- equation 1}$$

where x = the number of heavy metals and E_r = a single ecological risk factor computed as:

$$E_r = PI \times T_r \quad \text{- equation 2}$$

and the T_r is “toxic- response” factor for a given metal; Cd = 30, Cr = 2, Cu = 5, Ni = 5, Pb = 5, and Zn = 1 (Hakanson, 1980). Fe was excluded because no PERI value for Fe. Four classes of sediment quality were distinguished based on the potential ecological risk.

- ii) *Geo-accumulation index (Igeo)*: This heavy metal index measures the degree of contamination (Islam *et al.*, 2014; Muller, 1969). The index ranges from 0 (not contaminated) to 6 (extremely contaminated). It is calculated as:

$$I_{geo} = \log_2 \frac{C_n}{1.5 \times B_n} \quad \text{- equation 3}$$

where, C_n signifies the mean concentration of the i th heavy metal in the sediment samples analysed and B_n denotes the reference value.

iii) *Contamination Factor (C_f)*: The pollution level associated with a single heavy metal was assessed with the contamination factor (Hakanson, 1980). The C_f is expressed as the ratio between the concentration of each metal to the background value:

$$C_f = \frac{C_{\text{metal}}}{C_{\text{background}}} \quad \text{- equation 4}$$

where C_{metal} is the mean metal concentration in sediment, and C_{background} is the mean background value of the metal. The heavy metal standards were used as the background values. The ratio of the measured concentration to the natural abundance of a given metal had been proposed as the index. C_F is classified into four grades for monitoring the pollution of a single metal over a period of time (Ali *et al.*, 2016): low degree (CF < 1), moderate degree (1 ≤ CF < 3), considerable degree (3 ≤ CF < 6), and very high degree (CF > 6).

iv) *Degree of Contamination (DC)*: The environmental risks posed by sediments as a result of the presence of multiple trace metals was assessed by the degree of contamination (Hakanson, 1980). The equation is given by;

$$DC = \sum_{i=1}^n C_{f_i} \quad \text{- equation 5}$$

where C_{f1} is the contamination factor of metal. A DC > 24 is considered a very high degree of contamination while ≤ 6 is a low degree of contamination

v) *Nemerow Pollution Index (NPI)*: The NPI, also known as Row's Pollution Index, evaluates total pollutant level and determines which parameter contributes significantly to sediment quality (Hakanson, 1980; Liu *et al.*, 2017). It is calculated from the following formula:

$$NPI = \frac{C_n}{S_n} \quad \text{- equation 6}$$

where C_n is concentration of the nth parameter, S_n is prescribed maximum values of the nth parameter. Here, NPI ≤ 1 variables are responsible for only a minimal amount of sediment pollution while NPI > 1 parameters associated to sediment contamination are found to be present in excess amounts.

3.0 Results and Discussion

3.1 Physicochemical Characteristics of Sediments

The summary results for the physicochemical characteristics of sediments in the Escravos Estuary are presented in Table 1. The mean value for pH, conductivity, total organic carbon (TOC), sulphate, nitrate and phosphate were not significantly different across the five sampled stations along the estuary. All the parameters indicated above, except for sulphate were within the permissible limit as indicated in the Environmental Guidelines and Standard for the Petroleum Industry in Nigeria (EGASPIN, 2018). The mean pH value increased across the sampled station from station 1 to 5. The increase in pH from the upstream is expected, given the influence of tidal incursion and saltwater mixing from the ocean towards the estuary. The mean pH values of 7.24±0.13 was within the recommended limits of 6.5 - 8.5 (EGASPIN, 2018). Apart from pH, conductivity, TOC, sulphate, nitrate and phosphate did not follow

any trend across the study stations. The lack of obvious trend in the parameters could be attributed to the daily tidal movements and the consequent influence on the estuary. The non-significant variation in the mean values between the parameters across the sampled stations is similar to those reported by Anaero-Nweke *et al.* (2016) in their study of tidal influence on the distribution of discharged effluents on sediments in Okrika Creek, Port Harcourt, Rivers State. Conductivity ranged from 5084.17 ± 229.19 to 7116.00 ± 243.36 $\mu\text{S}/\text{cm}$ in the sampled stations with a mean of 6235.9 ± 636.00 $\mu\text{S}/\text{cm}$. The observed conductivity levels in the sediments compared with those reported by Anaero-Nweke *et al.* (2016). TOC ranged from 0.71 ± 1.00 to $0.91 \pm 1.39\%$ for the sampled station with a mean of $0.77 \pm 1.65\%$. The value compared with levels reported for Zmeica Lake (0.77%) (Catianis *et al.*, 2018), but lower than that reported for Golovita Lake (1.58%) and Sinoie Lake (2.55%) - a Ramsar site in Romania (Catianis *et al.*, 2018) and higher than that reported for Leizhou Peninsula (0.42%) in China (Xia *et al.*, 2022). Low TOC has implication for the survival of benthic organisms. Nutrients such as sulphate, nitrate and phosphate ranges from 227.50 ± 75.48 to 397.17 ± 239.59 mg/kg, 2.04 ± 1.09 to 3.53 ± 1.46 mg/kg and 0.94 ± 0.18 to 1.38 ± 0.39 mg/kg across the sampled stations, with a mean of 299.67 ± 259.54 mg/kg, 2.78 ± 1.58 mg/kg and 1.10 ± 0.17 mg/kg respectively. The increased level of sulphate reported above the permissible limit could be attributed to additives used in petroleum and gas exploration wells prevalent within the region. The observed mean sulphate and phosphate level were higher than the reported 30.3 to 185.5 mg/kg and <0.05 mg/kg respectively for Okrika Creek (Anaero-Nweke *et al.*, 2016).

3.2 Heavy Metals Distribution in Sediments

The mean values of heavy metals such as Fe, Cd, Pb, Zn and Cu (Table 1) reported in sediments of the estuary across the sampled stations were higher than the recommended limited (EGASPIN, 2018) established by the Nigerian Upstream Petroleum Regulatory Commission (formerly DPR). No significant differences were observed in the mean values of heavy metals across the sample stations. The increased levels of heavy metals present in sediments is majorly associated with wastewater effluent from petroleum and gas production and from artisanal refining operations prevalent within the region. The metals reported in our study are metals consistent with impurities from petroleum and gas activities. The values of heavy metals reported in this study were far higher than that reported in the water and sediment of the New Calabar River (Davies and Ekperusi, 2021). This is expected as the air, water and soil of the study location are continuously exposed to the release of untreated and poorly treated effluents from oil and gas activities entering the estuary. Contaminants like heavy metals settles at the bottom sediments with direct and indirect impact on benthic and demersal species. Among the heavy metals, Fe had the highest concentration (3392.84 ± 2318.30) and this was found to be consistent with results of Tunde and Oluwagbenga (2020) in their evaluation of sediment and heavy metals contamination in Ondo coastal area. This unusually high concentration of iron may be associated with the rich iron-bearing minerals in sedimentary depositions within the Niger Delta region. The distribution

of the various heavy metals in sediments is in the decreasing order of $\text{Fe} > \text{Zn} > \text{Pb} > \text{Cu} > \text{Cd}$. Similar trends have been reported by other studies with iron usually high and cadmium being the lowest among the metals in sediments (Davies and Ekperusi, 2021; Ekperusi *et al*, 2022).

Table 1. Summary of physicochemical, heavy metals and TPH (mean±SD) condition of sediments in Escravos Estuary.

Parameter	Station 1	Station 2	Station 3	Station 4	Station 5	Total	F-value	Sig	Limit**
pH	7.14±0.42	7.14±0.37	7.28±0.23	7.28±0.69	7.38±0.50	7.24±0.44	0.277	.890	6.5 – 8.5*
Cond (µS/cm)	6769.17±2557.08	7116.00±2432.36	5084.17±2290.19	5765.50±2758.44	6444.67±2907.53	6235.90±2523.78	0.589	.674	Not Defined
TOC (%)	0.76±1.36	0.71±1.00	0.91±1.39	0.73±1.46	0.73±1.60	0.77±1.28	0.021	.999	
SO ₄ (mg/kg)	397.17±239.59	266.17±148.51	227.50±75.48	277.17±132.32	330.33±163.39	299.67±160.87	1.002	.425	
NO ₃ - (mg/kg)	3.53±1.46	2.65±1.21	2.04±1.09	2.72±1.13	2.95±1.30	2.78±1.26	1.126	.367	
PO ₄ (mg/kg)	1.12±0.16	0.94±0.18	0.98±0.57	1.07±0.56	1.38±0.39	1.10±0.41	1.040	.406	
Fe (mg/kg)	3603.57±427.56	3487.19±434.99	3314.21±345.11	3260.41±509.45	3298.83±700.67	3392.84±481.49	0.519	.723	0.3
Cd (mg/kg)	8.95±4.10	7.52±3.74	5.62±3.24	6.12±2.79	8.35±3.90	7.31±3.57	0.944	.455	0.8
Pb (mg/kg)	14.76±4.27	14.79±3.47	11.09±3.69	15.21±5.34	14.81±4.57	14.13±4.30	0.943	.456	85
Zn (mg/kg)	37.54±15.63	43.66±21.04	28.03±10.34	41.61±24.86	33.01±12.48	36.77±17.43	0.775	.552	140
Cu (mg/kg)	9.59±1.64	9.73±1.86	7.85±2.74	9.47±1.58	9.94±2.54	9.31±2.12	.931	.462	36
TPH (mg/kg)	65.30±2.11	61.42±1.03	72.64±14.05	65.89±12.13	68.79±37.44	66.81±17.79	.300	.875	50

Source: ** (EGASPIN, 2018); * (WHO, 2008)

3.3 Total Petroleum Hydrocarbons in Sediments

The mean TPH concentration ranged from 61.42 ± 1.03 to 72.64 ± 14.05 mg/kg across the sampled stations with a mean of 66.81 ± 17.79 mg/kg (Table 1). The mean TPH value was lower than the reported range of 126.47 - 2328.82 mg/kg for the Okrika Creek (Anaero-Nweke *et al.*, 2016), but higher than the recommended level of 50 mg/kg (EGASPIN, 2018). Sediment act as sink and a major reservoir for hydrocarbon and other environmental pollutants (Olayinka *et al.*, 2019; Ambade *et al.*, 2023). The buildup of hydrocarbons in sediments could be taken up by benthic and demersal organisms and move up the food chain with potential health implications on humans that consumed contaminated seafood (Akinnusotu *et al.*, 2023; Cui *et al.*, 2023).

3.4 Pollution Indicators and Ecological Risk of Heavy Metals in Sediments

The observed PERI classification risk index in all sampled stations was < 400 indicating a considerable ecological risk for the biological communities in the estuary (Table 2). The observed risk index compares to the reported value of 260.87 using the concentrations of the heavy metals in the bottom sediment of the Lower Niger river (Ikpesu and Ezenwaka, 2018).

Table 2. Potential ecological risk index classification for heavy metals in the Escravos Estuary

	Class	PER1	Ecological Risk
Station 1	2	338.09	Considerable Ecological Risk
Station 2	2	284.53	
Station 3	2	212.69	
Station 4	2	232.01	
Station 5	2	315.61	
CLASSIFICATION			
Class	PERI	Ecological Risk	
0	<110	Low risk	
1	<110≤RI<200	Moderate risk	
2	200≤RI<400	Considerable Ecological Risk	
3	>400	Severe Ecological Risk	

The geo-accumulation index of Pb, Zn and Cu in the estuary was < 0 indicating no contamination in all the sampled stations. However, the geo-accumulation index for Cd indicated moderately to heavily contaminated sediments (class 3) in all the sample stations (Table 3). The observed geo-accumulation index in all the stations for Pb, Zn and Cu compare to those reported by Wardani *et al.* (2020) in their sediment quality assessment of Banten Bay. The results for Cd thus indicated high level of anthropogenic influence on the ecosystem with consequent implications for ecosystem health.

Table 3. Geo-accumulation index for heavy metals in sediments of the Escravos Estuary

Heavy metal	Igeo index				
	Station 1	Station 2	Station 3	Station 4	Station 5
Cd	2.9	2.6	2.2	2.4	2.8
Pb	-3.1	-3.1	-3.5	-3.1	-3.1
Zn	-2.5	-2.3	-2.9	-2.3	-2.7
Cu	-2.5	-2.5	-2.8	-2.5	-2.4

Classification of Geo Accumulation Index

Index Class	Igeo Value	Level of contamination classification
0	$I_{geo} < 0$	Uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately to heavily contaminated
4	$3 < I_{geo} < 4$	Heavily contaminated
5	$4 < I_{geo} < 5$	Heavily to extremely contaminated
6	$I_{geo} > 5$	Extremely contaminated

Results concerning the contamination factor and degree of contamination of heavy metals in the sediments are presented in Table 4. Using the classification according to Ali *et al.* (2016), the C_F for Cd and Pb was > 6 in all the sampled stations, while Cu showed $C_F > 6$ in four of the five sampled stations indicating very high degree of contamination. The observed C_F for Cu were higher than that reported by Nubi *et al.* (2022) in their study of the spatial distribution and risk assessment of heavy metals in South Western coastal waters. The C_F for Zn however lies in the region < 3 and is therefore classified as considerable degree of contamination. In all, the degree of contamination (DC) of heavy metals was > 24 (Table 4) in all the sampled station indicating a very high heavy metals contamination of the sediments in the Escravos Estuary.

Table 4. Contamination factor (C_f) and degree of contamination (DC) of heavy metals in sediments of the Escravos Estuary

	$C_{Background}$	C_{f1}	C_{f2}	C_{f3}	C_{f4}	C_{f5}
Cd	0.8	2983.3	2506.7	1873.3	2040	2783.3
Pb	85	1476	1479	1109	1521	1481
Zn	140	2.5	2.9	1.9	2.8	2.2
Cu	36	6.4	6.5	5.2	6.3	6.6
D.C (ΣC_{fn})		4468.2	3995.1	2989.4	3570.1	4273.2

The NPI of heavy metals in sediment in the estuary is presented in Table 6. The results from the present study indicate that conductivity, sulphate, Cd and TPH contributed significantly to sediment pollution across the sample stations. However, Pb, Zn, Cu, pH, nitrates and phosphates contributed minimally to sediment pollution in the estuary. The observed NPI for this study (Table 5) were far below the levels reported by Ajani *et al.* (2021) in their evaluation of the pollution status of Lagos coastal water and sediments.

Table 5. Nemerow pollution index of sediments in the Escravos Estuary

	Station 1	Station 2	Station 3	Station 4	Station 5
pH	0.8	0.8	0.9	0.9	0.9
Cond	2.7	2.8	2.0	2.0	2.6
TOC	0.4	0.4	0.5	0.5	0.4
SO ₄	4.0	2.7	2.3	2.3	3.3
NO ₃	0.4	0.3	0.2	0.2	0.3
PO ₄	0.3	0.3	0.3	0.3	0.4
Cd	11.2	9.4	7.0	7.0	10.4
Pb	0.2	0.2	0.1	0.1	0.2
Zn	0.3	0.3	0.2	0.2	0.2
Cu	0.3	0.3	0.2	0.2	0.3
TPH	1.3	1.2	1.5	1.5	1.4

3.2 Macrobenthic Invertebrates

The abundance, distribution, and diversity of macrobenthic invertebrates reported during the study are shown in Figure 2. The current study counted 65 individuals from 7 species, 7 genera, 7 families and 3 phyla. An earlier study in the Escravos Estuary recorded 33 taxa (Olomukoro and Dirisu, 2011). Arthropoda like *Brachyura spp* accounted for 38%, while *Melanoides tuberculata* recorded 20%, followed by *Pyrgospira Candace* (17%) while other species were $\leq 9\%$. The prevalence of *Brachyura spp* is an indication of their capacity to thrive in estuary and mangrove swamps environments by clinging to mangrove roots.

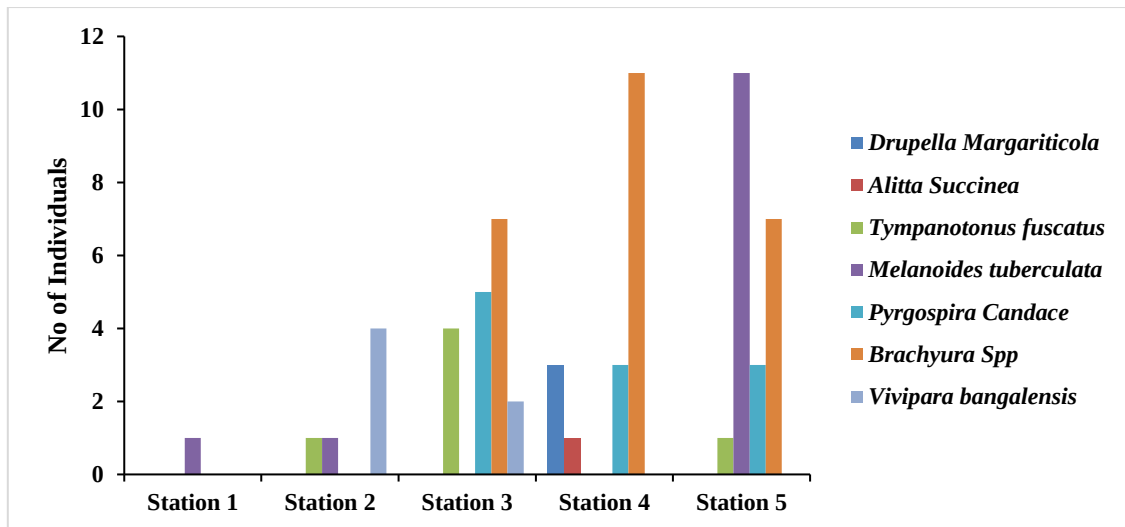


Figure 2. Spatial variation of macrobenthic invertebrate assemblage in the Escravos Estuary

Molluscs (60%) dominated the macroinvertebrates phyla (Figure 3), followed by Arthropoda (38%) and the least was Annelida (2%). This is consistent with the report of Olomukoro and Dirisu (2011) and Onyena *et al.* (2021) that reported the abundance of molluscs over other phyla in the same estuary. The relative and mean abundance of the macroinvertebrates in the various sites shows the heterogeneity indices of the study sites and the low number of individuals. Figure 4 illustrates that the abundance of macroinvertebrate species could be affected by seasonal changes. *Brachyura* sp. and *Melanoides tuberculata* were observed to be more during the peak of dry months (January and February). The highest number of individuals was found in station 5 (22), followed by stations 4 and 3 (18), while stations 1 and 2 recorded ≤ 6 . The factor responsible for the increase abundance of macrobenthic organisms towards the upstream could be associated with less petrochemical production towards stations 5, 4 and 3, compared to stations 1 and 2.

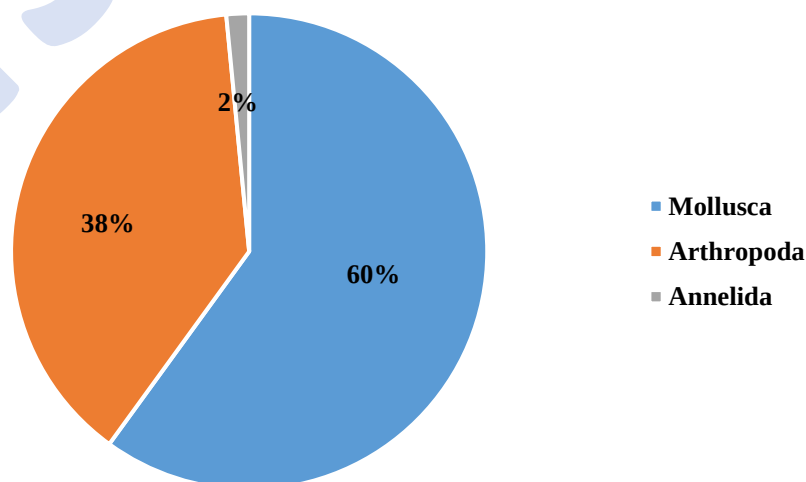


Figure 3. Percentage phylum distribution in Escravos Estuary

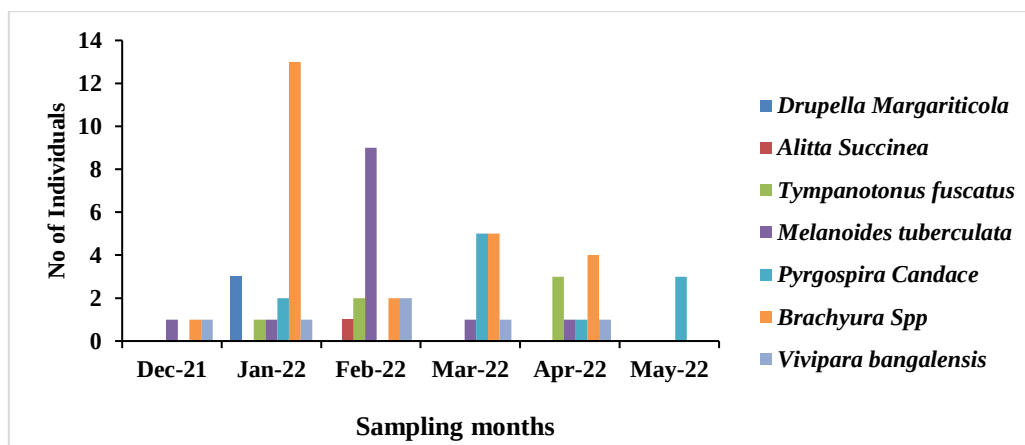


Figure 4. Temporal variation of macrobenthic invertebrate assemblage in the Escravos Estuary

3.3 Biological Indices

The low Simpson index across sampling stations in the present study showed a low level of diversity in the community assemblage. Although the overall diversity recorded in the study is minimal, stations 2 to 5 recorded greater diversity than station 1 (Table 6). The high level of sediment pollution in station 1 and 2 resulted in the reduced and lowest number of individuals. It is possible that the nature of the substratum is responsible for the low levels of diversity and abundance that were observed in this study. The species richness and equitability distribution of macrobenthic invertebrates in the sampled stations was lowest in station 1. The paucity of macrobenthic invertebrates can be attributed to continuous release of oily waste from artisanal refineries and oil production platforms in the station and the consequent pollution of the estuary. Due to widespread ecological conditions in an ecosystem, some macroinvertebrates have a greater chance of thriving in a particular ecosystem than others. The present study shows that the species distribution in the estuary was not uniform and was site specific (equitability test was <1). The diversity and richness of macroinvertebrates in the estuary are low compared to previous works conducted around the area (Imoobe, 2002; Onyena *et al.*, 2021) and less than what has been recorded from other Nigerian coastal waters (Nkwoji *et al.*, 2016; Yakub and Igbo, 2014). Aside wastewater from oil and gas activities, the frequent release of effluent discharges with large suspended material loads and organic waste from runoff may have resulted in bottom sediment smothering processes. Sediments are sinks for pollutants and also habitats for macroinvertebrates. The pollution of sediments to the extent observed in this study therefore portends grave consequences for benthic organisms and by extension the ecosystem.

Table 6. Community structure of macrobenthic invertebrates in the study area.

	Station 1	Station 2	Station 3	Station 4	Station 5
Taxa	1.0	3.0	4.0	4.0	4.0
Individuals	1.0	6.0	18.0	18.0	22.0
Dominance	1.0	0.5	0.3	0.4	0.4
Simpson	0.0	0.5	0.7	0.6	0.6
Shannon	0.0	0.9	1.3	1.1	1.1
Evenness	1.0	0.8	0.9	0.7	0.8
Margalef	0.0	1.1	1.0	1.0	1.0
Equitability	0.0	0.8	0.9	0.8	0.8

3.4 Relationship Between Physicochemical Characteristics of Sediments and Macrobenthic Invertebrates

The relationship between the physicochemical characteristics and macrobenthic invertebrates was assessed using Pearson's correlation. The pH of the sediment had a moderately positive correlation with *Drupella margariticola* (.410) and a strong positive correlation with *Brachyura* sp (.484). Phosphate negatively correlated with *Vivipara bangalensis* (-.414). Iron had a strong positive correlation with *Melanoides tuberculata* (.471) and a moderately negative correlation with *Pyrgospira candace* (-.378). Zinc positively correlated strongly with *Alitta succinea* (.543) while total petroleum hydrocarbons positively correlated strongly with *Melanoides tuberculata* (.612). A strong negative association was reported between pH and *Chaetogaster* sp, *Diplogaster* sp, *Nadium osborni*, *Nais simplex* and *polypodium* sp. Nitrate had a negative relationship with *Epicordulia* sp and *Polypodium* sp (Ekperusi *et al.* 2022). Arimoro *et al.* (2007) reported that nitrate was positively correlated with the macroinvertebrate density of Ase River.

4.0 Conclusion

The Escravos Estuary is an important brackish water ecosystem with crucial ecological and human importance. The findings of our study have shown the high degree of heavy metals contamination in the sediment of the estuary. This has greatly impacted the diversity and distribution of macrobenthic invertebrates. Urgent action is recommended to curtail the disposal of untreated oily waste into the estuary to forestall and mitigate the ecological degradation and decline of biodiversity in the estuarine ecosystem.

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Declaration of interest

Authors declare no conflict of interest.

Contribution of authors

P.A. Bariweni and A.P. Onyena conceived and designed the study. Material preparation, data collection and analysis were performed by P.A. Bariweni, A.P. Onyena, M.E. Okiotor and A.O. Ekperusi. The draft manuscript was written by A.P. Onyena and A.O. Ekperusi. All authors read and approved the final manuscript.

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