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Ecological and Human Health Risk Assessment of Heavy Metal in Sediment and Demersal Fish Species in Western Offshore Nigeria, Gulf of Guinea

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ABSTRACT. This study was focused to assess the contamination status of heavy metals in sediments, and human health risks associated with fish consumption from western Nigeria offshore in the Gulf of Guinea. Triplicate samples of demersal marine fish species and sediments were collected from five stations (fishing ground) and analysed for heavy metals [mercury (Hg), cadmium (Cd), and lead (Pb)] and metalloid [arsenic (As)] using ICP-OES (inductively coupled plasma optical emission spectrometry) adopted USEPA 200.7 standard method. The metals/metalloid concentrations in demersal fish species and sediment fell below the FAO/WHO permissible limits and sediment quality guidelines (SQG) [probable effect level (PEL) and threshold effect level (TEL)]. The ecological indices [probable contamination index (PCI), mean effect level quotients, newly modified hazard quotient (mHQ), and hazard quotient (HQ)] revealed low contamination level of heavy metals in sediment. The hazard index (HI) of metals in fish species associated with human health fell below the recommended threshold of 1 with no significant health risk to the consumers. The target cancer risk (TCR) of Cd and Pb in the fish species were below the regulation range of 1.0×10^{-6} to 1.0×10^{-4} set by the USEPA. The cluster analysis revealed two clusters. Cluster 1 (C1) showed that Cd was significantly accumulated in the sediment. Cluster 2 (C2) showed significantly low bioaccumulation of Hg, Cd, Pb, and As in fish species across all stations. The ecological and health risk assessment indices generally established low potential adverse effect on demersal marine fish species due to the overall low ecological severity risk associated with heavy metals/metalloids in sediment. Hence, consumers of fisheries resources from western off Nigeria coast are relatively safe from being exposed to any non-carcinogenic and carcinogenic health risk.

Keywords: demersal marine fish, sediment, heavy metals/metalloids, pollution indices

1. Introduction

In recent times, aquatic pollution has increased as the human population spontaneously grows around coastal and marine environments. However, demersal marine organisms are good indicators of pollution due to their high affinity to bioaccumulate contaminants in their muscle tissues which could give rise to health risk associated with human consumption (Han et al., 2021). The consumption of fish is of great significance due to its nutrients such as polyunsaturated fatty acids, vitamins, and high-quality protein. Consequently, fish consumers are faced with several health hazards due to bioaccumulated metals in fish.

In this light, demersal marine organisms which includes fish species are excellent bio-indicators to evaluate the metal levels within marine environments (Pandey et al., 2014). Ahmad and Al-Mahaqeri (2015) consider fish as fundamental biomarkers to monitor pollutants within the marine environment for various reasons such as higher trophic levels along the food chain; the toxicity of these measured metals can significantly affect the physiological and behavioural form of the fish and fish serves as an essential constituent to the human diet.

The Gulf of Guinea region is in Africa and is located within the West and Central African coast lines and the surrounding territorial waters of the Atlantic Ocean. Geographically speaking, the Gulf of Guinea is made up of the maritime area located in the western part of the African continent and north-eastern part of the Atlantic Ocean to the east of the Greenwich meridian line. Geographically The coastline of the Gulf of Guinea forms part of the western edge of the African tectonic plate and corresponds remarkably to the continental margin of South America running from Brazil to the Guianas (Abubakar, 2016).

Sediments also serve as a key repository of heavy metals within the marine environment, as they are majorly stored and transported in particulate matter (Bruder et al., 2002). Hence, this research was focused to assess the ecological and associated human health risk of heavy metals in sediments and demersal marine fish that could provide historical information on pollutant

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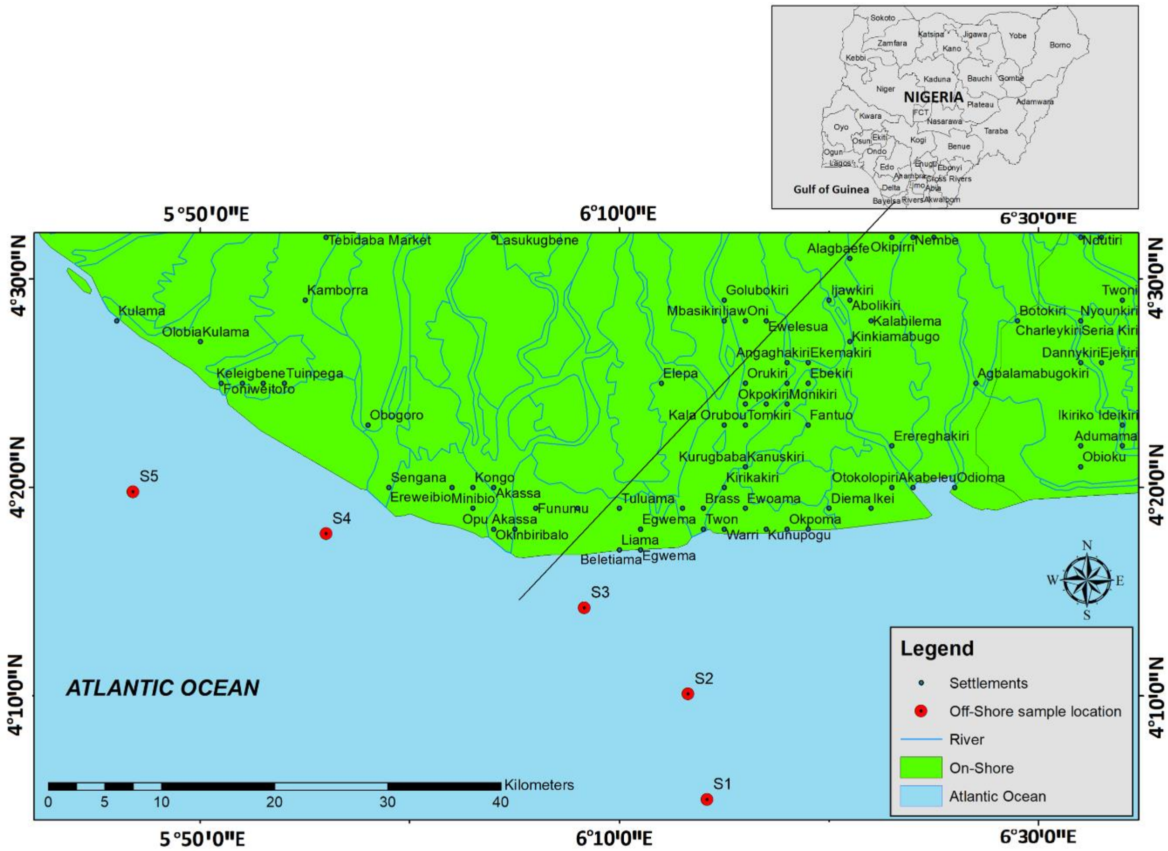


Figure 1. Map depicting sampling stations (fishing grounds) within the Gulf of Guinea.

inputs at specific hotspots, as well as serve as an indicator to reflect the current status of the marine ecosystem. The objectives of this research were to (1) ascertain the heavy metal/metalloid levels in sediment and demersal marine fish species, (2) establish the contamination status of sediment using ecological indices, and (3) evaluate the human health risk of heavy metals and metalloids in demersal marine fish species from fishing grounds of the Western Offshore Nigeria, Gulf of Guinea.

2. Materials and Methods

2.1. Study Area

The study area is situated at the Western offshore flank within the Gulf of Guinea, which lies between longitudes of 04°00′ and 04°35′ E, and latitudes of 06°00′ and 06°15′ N, which is characterized by a tropical climate with a high temperature and humidity. The study areas are designated fishing grounds. The fish stock assessments were carried out on five sampling hotspots (fishing grounds) along western offshore Nigeria, Gulf of Guinea in October 2021 (Figure 1). The Niger Delta sedimentary basin of Nigeria contains more than 12 km of marine and deltaic sediments. The Niger delta is located in the Gulf of Guinea, Central West Africa, at the culmination of the Benue Trough and is considered one of the most prolific hydrocarbon provinces in the world (Corredor et al, 2005). The geologic sequence of the Delta flank consists of three main subsurface lithostratigraphic units (Benin, Agbada and Akata formations) which are overlain by different types of Quaternary deposits and ranges in age from tertiary to recent (Dada et al., 2015; Didei and Akana, 2016). The Formations consists of alternating sequence of gravel, sand (fluviatile, coastal and fluviomarine), silt, clay, alluvium and marine shale (Ekwere et al., 2013).

2.2. Sample Collection

Fifteen demersal fish species (*Selene dorsalis*, *Galeoides decadactylus*, *Brachydeuterus auritus*, *Pseudotolithus senegalensis*, *Cynoglossus browni*, *Chloroscrombrus chrysurus*, *Sphyraena guachancho*, *Sardinella maderensis*, *Penaeus notialis*, *Sphyraena piscatorum*, *Lutjanus goreensis*, *Cynoponticus ferox*, *Rhizoprionodon acutus*, *Pagellus ehrenbergi* and *Pseudotolithus elongatus*) and surface sediments were collected. Demersal fishes were caught using a demersal trawl net attached to navigating RV Bayagbona vessel at an average depth of 31.2 m, and sediment was collected using 0.1 m^2 van Veen grab sediment sampler. Triplicates of each fish species were collected in Ziploc bags, and placed in the research vessels cold-room of –40 °C, while the pooled sediments were stored in foil paper, appropriately labeled and transported to the Biological Oceanography laboratory, NIOMR for further analysis.

2.3. Heavy Metals/Metalloid Analysis

Sample (surface sediments and fish muscle) preparation

Table 1. Sediment Quality Guidelines (SQG) of Heavy Metals and Metalloid (Unit: mg/kg)

SQG	As	Hg	Cd	Pb	References
PEL	17	0.486	3.53	91.3	MacDonald et al. (2000)
ERM	85	1.3	9	110	Benson et al. (2018)
ERL	33	0.15	5	35	
TEL	5.9	0.17	0.6	35	
MET	7	0.2	0.9	42	
SEL	33	2	10	250	
TET	17	1	3	170	
GBG-Shale Standard	13	0.4	0.3	20	Turekian and Wedepohl (1961)

Note: Sediment quality guideline: PEL - Probable effect level, ERM - Effects range median, ERL - Effects range low, TEL - Threshold effect level, SEL - Severe effect level, MET - Minimal effect threshold, and TET - Toxic effect threshold.

and analyses of As, Hg, Cd, and Pb in samples were performed with USEPA. 200.7 standard method using ICP-OE spectrometry; Agilent Expert Software adopted from Paul (2011) and Qin et al. (2021) carried out at the laboratory of Technology Partners International. A 0.500 ± 0.001 g of an air-dried, (particle size < 2 mm) of sediment and fish muscle samples, were placed into a digestion vessel. Then 2 mL (1:1) HNO_3 and 5 mL (1:4) HCl was added. The mixture was swirled to mix, capped, and refluxed for 1 hour at 95 ℃ on a heat block. The digestate was allowed to cool to 25 ℃, and then made up to 30 mL with deionized water. The solution was filtered through Whatman #42 filter, and then saved for the determination of the elements. Analysis of a quality control (QC) and quality assurance (QA) were performed for initial and periodic verification of calibration standard solutions, in order to verify instrument performance. The QC was obtained as Certified Reference Material (CRM) and prepared in the same acid mixture as the calibration standards.

2.4. Ecological Risk Assessment in Sediment

Probable contamination index (PCI) of metal *i* was calculated using Equation (1) proposed by Dauvalter and Rognerud (2001):

$$\mathrm{PCI}_i = \frac{C^i_{\max}}{C_{bkg}} \tag{1}$$

where $C_{\max}$ is maximum concentration of metal in sediment, and C_b is geochemical background concentration of metal with reference average shale (Benson et al., 2018). PCI classification grade of contamination in sediment includes: PCI < 1 indicates low contamination, 1 < PCI < 3 indicates moderate contamination, and PCI > 3 indicates severe or very severe contamination (Ahamad et al., 2020).

2.5. Ecotoxicological Assessment of Heavy Metal Concentrations in Sediments

The sediment quality of the metal concentrations was characterized compared the effects range low (ERL), effects range median (ERM), probable effect level (PEL), threshold effect level (TEL), severe effect level (SEL), and minimal effect threshold (MET) (Table 1). Equation (2) shows the formulae used to calculate the mean PEL quotient:

$$\mathrm{mPEL_Q} = \frac{\sum_{i=1}^{n}(C_i / \mathrm{PEL}_i)}{n} \tag{2}$$

where n is sum of the metals considered, C is metal concentration, and PEL is probable effect level value of the individual metal (Darwish et al., 2021).The $\mathrm{mPEL_Q}$ is categorized (Paches et al., 2019) into four grades: $\mathrm{mPEL_Q} \leq 0.1$ indicates low degree of contamination with 8% probability of being toxic; $\mathrm{mPEL_Q}$ = 0.11 ~ 1.5 indicates medium-low degree of contamination with 21% probability of being toxic, $\mathrm{mPEL_Q}$ = 1.51 ~ 2.3 indicates high-medium degree of contamination with 49% probability of being toxic and mPELQ > 2.3 indicates high degree of contamination with 73% probability of being toxic respectively (Long et al., 2006; Benson et al., 2018).

The mean effect range median quotient according to Santos et al. (2020) was calculated using Equation (3):

$$\mathrm{mERM_Q} = \frac{\sum_{i=1}^{n}(C_i / \mathrm{ERM}_i)}{n} \tag{3}$$

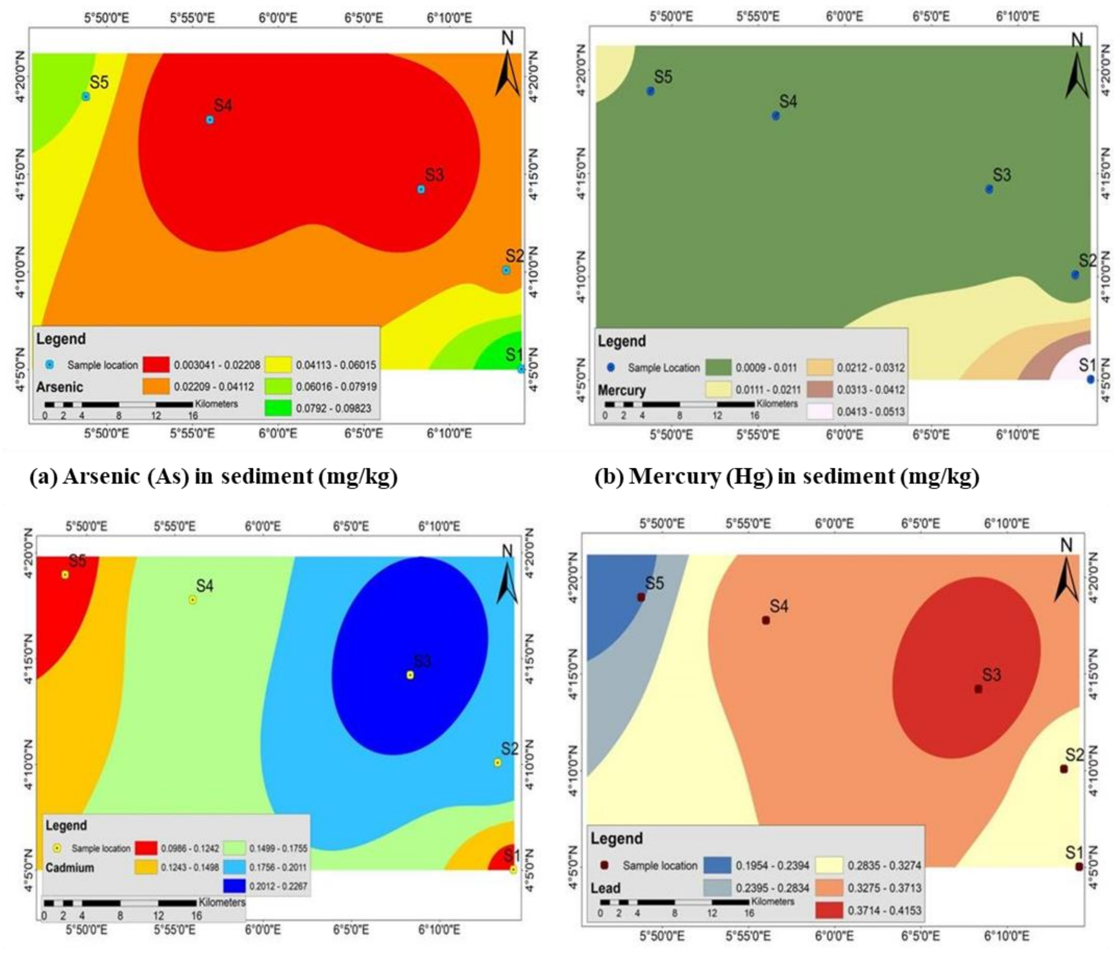
where ERM_i is the ERM for metal *i*. The categorized grades: $\mathrm{mERM_Q} \leq 0.1$ indicates low priority site with 9% probability of being toxic, $\mathrm{mERM_Q}$ = 0.1 ~ 0.5 indicates medium-low priority site with 21% probability of being toxic, $\mathrm{mERM_Q}$ = 0.5 ~ 1.5 indicates high-medium priority site with 49% probability of being toxic, and $\mathrm{mERM_Q} > 1.5$ indicates high priority site with 76% probability of being toxic respectively (Paches et al, 2019).

2.6. Hazard Quotients (HQ)

The hazard quotient of metals in sediment was computed using Equation (4):

$$\mathrm{HQ} = \frac{C_{metal}}{\mathrm{SQG}} \tag{4}$$

where C_{metal} is metal concentration and SQG is sediment quality guideline of threshold effects level (Long et al., 2006; Paul et al., 2021). Classification of hazard quotients: HQ < 0.1 indicates no adverse effects; 0.1 < HQ < 1 indicates potential hazards; 1 < HQ < 10 indicates moderate hazards; HQ > 10 indicates high hazards (Feng et al., 2011; Benson et al., 2018).



(a) Arsenic (As) in sediment (mg/kg) **(b) Mercury (Hg) in sediment (mg/kg)**

(c) Cadmium (Cd) in sediment (mg/kg) **(d) Lead (Pb) in sediment (mg/kg)**

Figure 2. Geospatial distribution of (a) As, (b) Hg, (c) Cd, and (d) Pb concentrations across the fishing ground (stations).

2.7. Newly Modified Hazard Quotient (mHQ)

The newly mHQ was computed to ascertain the degree of contamination by individual heavy metal (Rahman et al., 2012). Benson et al. (2018) proposed the newly modified approach which enables the assessment of contamination by comparing metal concentration in sediment with adverse ecological effect distributions for differing threshold levels (TEL, PEL and SEL). The newly modified hazard quotient (mHQ) for metals in sediment was computed using Equation (5):

$$\text{mHQ} = \left[C_i \left(\frac{1}{\text{TEL}_i} + \frac{1}{\text{PEL}_i} + \frac{1}{\text{SEL}_i} \right) \right]^{1/2} \tag{5}$$

where C_i is concentration of heavy metal; TEL_i, PEL_i, and SEL_i are sediment quality threshold levels for i^{th} metal. The newly modified hazard quotients are classified for its degree of contamination by individual metal. The newly modified hazard quotient classification for degree of contamination are as follows: mHQ > 3.5 means extreme severity; 3.0 < mHQ < 3.5 indicates very high severity; 2.5 < mHQ < 3.0 means high severity; 2.0 < mHQ < 2.5 represents considerable severity; 1.5 < mHQ < 2.0 means moderate severity; 1.0 < mHQ < 1.5 means low severity, and 0.5 < mHQ < 1.0 indicates very low severity of contamination.

2.8. Health Risk Assessment in Demersal Marine Fish

2.8.1. Estimated Daily Intake (EDI) of Metals

The estimated daily intake was computed using Equation (6) (Islam et al., 2014):

$$\text{EDI} = \frac{\text{Mc} \times \text{IR}}{\text{Bw} \times 10^{-3}} \tag{6}$$

where Mc is metal concentration in the fish muscle; IR is ingestion rate, 19.5×10^{-3} kg/day (Baki et al., 2018); Bw is average body weight for adult as 60 kg (USEPA, 2005).

2.8.2. Target Hazard Quotient (THQ)

The target hazard quotient was computed using Equation (7) of USEPA Region III Risk-Based Concentration (USEPA, 2011) which estimates non-carcinogenic health risk associated with metal exposure:

$$THQ = \frac{(Mc \times FIR \times 10^{-3} \times EF \times ED)}{(RfD \times Bw \times ATn)} \quad (7)$$

where EF is exposure frequency (365 days/year); ED is exposure duration (life expectancy of adult = 70 years approx.); ATn is averaging time for non-carcinogens (365 days/year × ED); reference doses (RfD) for Cd: 1×10^{-3} µg g^{-1} day^{-1}, Hg: 1.6×10^{-4} µg g^{-1} day^{-1}, As: 3×10^{-4} µg g^{-1} day^{-1}, and Pb: 4×10^{-3} µg g^{-1} day^{-1} (USEPA, 2011).

2.8.3. Hazard Index (HI)

The hazard index was computed from summed up target hazard quotient of every metal as shown in Equation (8) (USEPA, 2011):

$$HI = THQ_{As} + THQ_{Cd} + THD_{Pb} + THD_{Hg} \quad (8)$$

2.8.4. Target Cancer Risk (TCR)

The target cancer risk (TCR) was calculated (Islam et al., 2014) using Equation (9):

$$TCR = \frac{(Mc \times FIR \times 10^{-3} \times CPSo \times EF \times ED)}{(Bw \times ATc)} \quad (9)$$

where ATc is averaging time for carcinogens (365 days/year × 70 years) (Ali et al., 2019), CPSo is carcinogenic potency slope, oral (mg/kg bw^{-1} day^{-1}) for Pb, and Cd are 0.009 and 0.6 mg/kg day^{-1}, respectively (Moslen and Miebaka, 2017; Paches et al., 2019).

2.9. Statistical Analysis

Analysis of variance (ANOVA), Hierarchical Cluster and Principal Component analysis of metals in sediment and fish were used to analyze the characteristic with similar sources using SPSS v.25 and PAST 4.10 (Hammer et al., 2001). ArcGIS 10.6 software was used for mapping of geospatial variability of heavy metals/metalloid in sediment.

3. Results and Discussion

3.1. Definitions and Basic Notations Geospatial Variation of Heavy Metal in Sediment

The heavy metals concentrations geospatial distribution (Hg, Cd, and Pb) and metalloid (As) in sediment across the stations are presented in Figure 2. The geospatial variation of As (green) and Hg (white) showed significant increase in concentrations as observed in station 1, while Cd (blue) and Pb (red) showed significant increase in concentrations at station 3. Generally, heavy metals/metalloids in sediment across the five stations in western offshore Nigeria, Gulf of Guinea were below TEL, ERL, MET, and TEC quality guidelines (MacDonald et al. 2000b).

3.2. Probable Contamination Index (PCI)

The PCI of metals are presented in a matrix plot (Figure 3). The mean PCI for As (0.01), Hg (0.10), and Pb (0.06) were below 1 (PCI < 1) which showed significant low contaminations across the sampling stations, while Cd (2.14) were higher than 1 which indicates moderate contamination levels across all stations. The PCI of heavy metals/metalloid follows a decreasing sequence; Cd > Hg > Pb > As in the sediment.

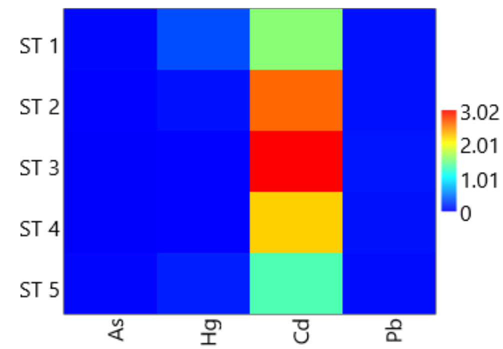


Figure 3. Matrix plot of probable contamination index.

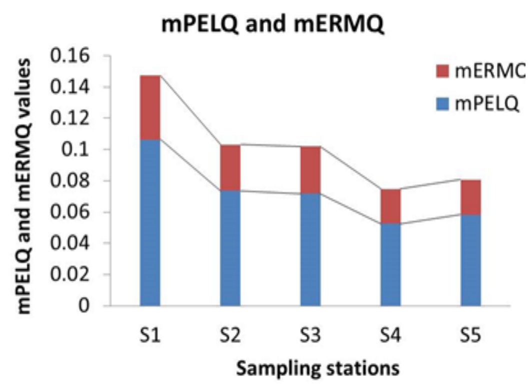


Figure 4. Spatial distributions of mPELQ and mERMQ in sediments.

3.3. Ecotoxicological Assessment and Mean Effect Level Quotient

Levels of Cd were higher than TEL by 100%, As by 3%, Hg by 24%, and Pb in 3.6% in sediment across all stations. For PEL, As was higher by 1.04%, Hg by 8.4%, Cd by 18.2%, and Pb by 1.4% in sediment. The estimated mean probable effects level quotient ($mPEL_Q$) had values below 0.1 across stations 2 ~ 5, while the estimated mERMQ values were also below 0.1 as presented in Figure 4. Generally, the mean probable effects level quotient ($mPEL_Q$) of the heavy metals/metalloid which fell below 0.1 which indicates low degree of contamination (≤ 0.1) notably with 8% minimal probability of being toxic, except for station 1 observed with medium to low degree contamination (0.11 ~ 1.5) with 21% probability of being toxic which corroborates with the findings of Paches et al. (2019), who also had $mPEL_Q$ ranged from medium to low degree contamination of heavy metals in sediments along the Spanish Mediterranean coastline. Likewise, mERMQ values were below 0.1 with low

Table 2. Estimated Hazard Quotients and Newly Modified Hazard Quotient for Sediment

Stations	Hazard Quotients				Modified Hazard Quotient			
	As	Hg	Cd	Pb	As	Hg	Cd	Pb
S1	0.067	0.738	0.774	0.034	0.20	0.36	0.66	0.25
S2	0.025	0.145	1.304	0.035	0.07	0.07	1.12	0.25
S3	0.005	0.031	1.512	0.047	0.01	0.02	1.30	0.35
S4	0.002	0.021	1.099	0.040	0.01	0.01	0.94	0.29
S5	0.051	0.272	0.657	0.022	0.15	0.13	0.56	0.16

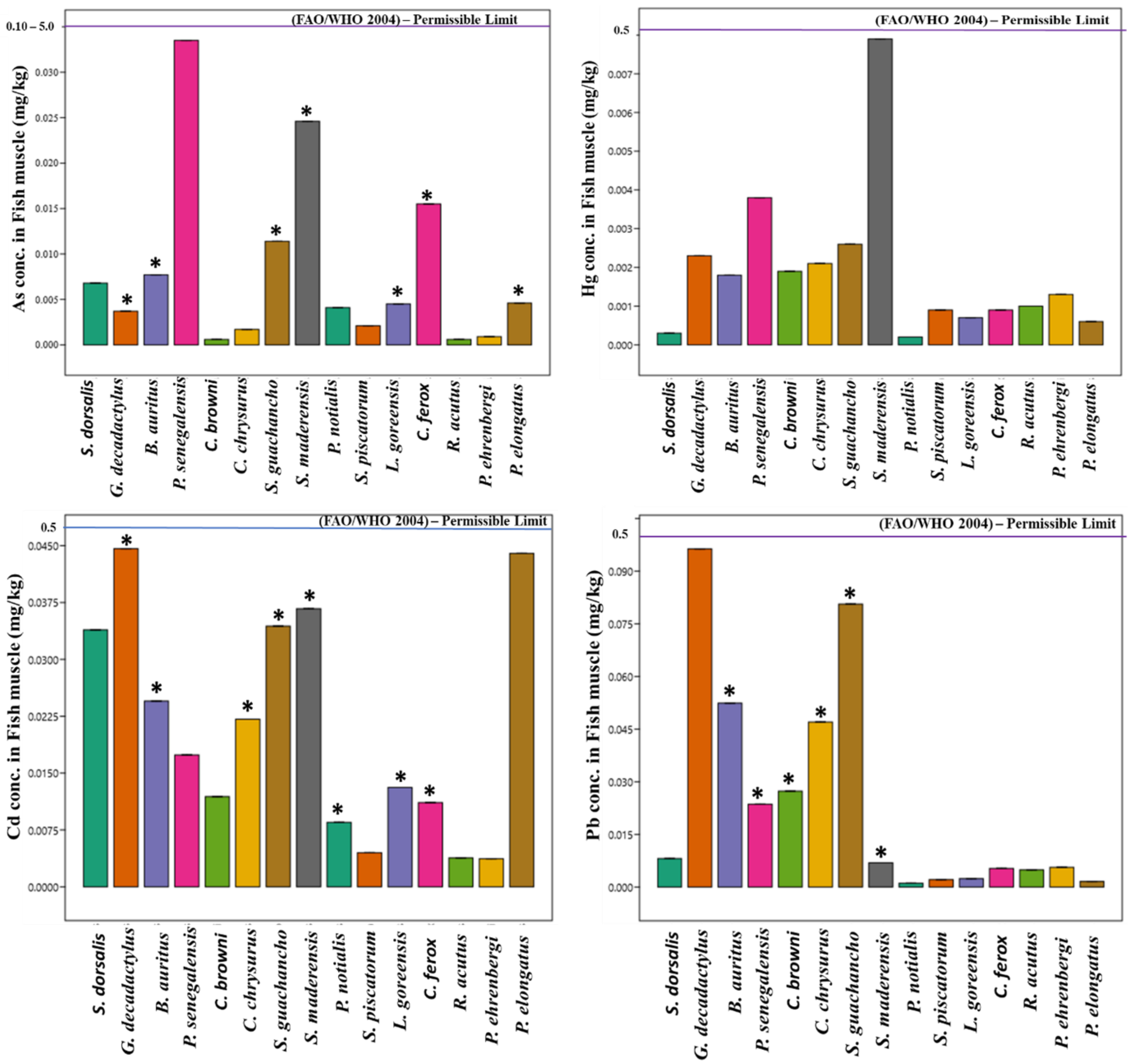


Figure 5. Mean variations of heavy metals/metalloids in muscle of fish species. Note: (*) indicates significant differences ($p < 0.05$) and comparison to permissible limits.

priority indicating low degree of contamination across all stations with 9% probability of being toxic in the sediment of western Nigeria offshore, Gulf of Guinea.

3.4. Hazard Quotients and Newly Modified Hazard Quotient for Sediment

The estimated HQ of As values ranged from 0.002 to 0.067, Hg values ranged from 0.021 to 0.74, Cd values ranged from 0.66 to 1.51, Pb values ranged from 0.02 to 0.05 (Table 2). As and Pb were below 0.1 (0.1 < HQ), while Cd had higher value greater than 1 at stations 2 ~ 4.

The newly modified hazard quotient of the sediment for As, Hg, and Pb was generally below 0.5, while Cd ranged from 0.56 to 1.30 across all stations off western Nigeria coast (Table

Table 3. Estimated THQ, HI And TCR of Metals in Demersal Fish Species

Demersal Fish Species	Target Hazard Quotient				Hazard Index	Target Cancer Risk	
	As	Hg	Cd	Pb		Cd	Pb
Selene dorsalis	1.72×10^{-5}	0.23×10^{-5}	2.57×10^{-5}	0.15×10^{-5}	4.67×10^{-5}	6.61×10^{-9}	2.37×10^{-11}
Galeoides decadactylus	0.94×10^{-5}	1.74×10^{-5}	3.38×10^{-5}	1.83×10^{-5}	7.89×10^{-5}	8.70×10^{-9}	28.2×10^{-11}
Brachydeuterus auritus	1.95×10^{-5}	1.37×10^{-5}	1.86×10^{-5}	0.99×10^{-5}	6.16×10^{-5}	4.78×10^{-9}	15.3×10^{-11}
Pseudotolithus senegalensis	8.47×10^{-5}	2.88×10^{-5}	1.32×10^{-5}	0.45×10^{-5}	13.1×10^{-5}	3.39×10^{-9}	6.90×10^{-11}
Cynoglossus browni	0.15×10^{-5}	1.44×10^{-5}	0.90×10^{-5}	0.52×10^{-5}	3.01×10^{-5}	2.32×10^{-9}	7.99×10^{-11}
Chloroscrombrus chrysurus	0.43×10^{-5}	1.59×10^{-5}	1.68×10^{-5}	0.89×10^{-5}	4.59×10^{-5}	4.31×10^{-9}	13.7×10^{-11}
Sphyraena guachancho	2.88×10^{-5}	1.97×10^{-5}	2.61×10^{-5}	1.53×10^{-5}	8.99×10^{-5}	6.71×10^{-9}	23.6×10^{-11}
Sardinella maderensis	6.22×10^{-5}	5.99×10^{-5}	2.78×10^{-5}	0.13×10^{-5}	15.1×10^{-5}	7.16×10^{-9}	2.02×10^{-11}
Penaeus notialis	0.44×10^{-5}	0.04×10^{-5}	0.28×10^{-5}	0.01×10^{-5}	0.77×10^{-5}	0.80×10^{-9}	0.01×10^{-11}
Sphyraena piscatorum	0.23×10^{-5}	0.18×10^{-5}	0.15×10^{-5}	0.02×10^{-5}	0.57×10^{-5}	0.41×10^{-9}	0.26×10^{-11}
Lutjanus goreensis	0.49×10^{-5}	0.14×10^{-5}	0.43×10^{-5}	0.02×10^{-5}	1.07×10^{-5}	0.88×10^{-9}	0.21×10^{-11}
Cynoponticus ferox	1.68×10^{-5}	0.18×10^{-5}	0.36×10^{-5}	0.04×10^{-5}	2.27×10^{-5}	3.02×10^{-9}	0.26×10^{-11}
Rhizoprionodon acutus	0.07×10^{-5}	0.20×10^{-5}	0.12×10^{-5}	0.04×10^{-5}	0.43×10^{-5}	0.12×10^{-9}	0.29×10^{-11}
Pagellus ehrenbergi	0.09×10^{-5}	2.64×10^{-5}	0.12×10^{-5}	0.05×10^{-5}	0.53×10^{-5}	0.18×10^{-9}	0.38×10^{-11}
Pseudotolithus elongatus	0.49×10^{-5}	0.12×10^{-5}	1.43×10^{-5}	0.01×10^{-5}	2.06×10^{-5}	0.90×10^{-9}	0.18×10^{-11}

2). The modified hazard quotient in descending sequence of severity associated with heavy metal contamination are listed as follows: Cd > Pb > Hg > As. The hazard quotients (HQ) of As, Hg, and Pb fell below 0.1 which implies the heavy metals/metalloid would not pose any potential adverse effect to aquatic organisms that burrows within the sediment. Conversely, the HQ of Cd with 1.30, 1.51, and 1.09 across station 2, 3 and 4 respectively fell within the range of $1 < HQ < 10$ which indicates moderate hazards within and surface sediment as classified by Paul et al. (2021). Furthermore, the newly mHQs for As, Hg and Pb fell below 0.5 which suggests very low severity of contamination, while Cd ranged between 0.5 and 1.0 which infers low severity of contamination. The newly modified hazard quotient in descending sequence of severity associated with heavy metal contamination are Cd > Pb > Hg > As. The outcome of this study agrees with Maanan et al. (2015) and Benson et al. (2018) from pollution assessment indices in sediment.

3.5. Heavy Metals in Demersal Marine Fish

The heavy metal levels in the muscle tissues of demersal marine fish species are presented in Figure 5. Mean levels of As, Hg, Cd, and Pb in muscles of the demersal fish species fell below the permissible limits by FAO/WHO (2004). Analysis of variance (ANOVA) revealed significant differences ($p < 0.05$) in Cd, Pb, and As of the fish species across sampled stations (fishing ground). High levels of metals affect living organisms and pose considerable environmental risks, which are contrary to the findings of Kortei et al. (2020) which clearly revealed sources of distress because of the potential health risk consequences from the intake of heavy metals through the consumption of water, fish and other similar aquatic organisms from the Ankobrah and Pra Rivers. Pollution is most notable within inland waters from either direct or indirect sources of discharges, compared to the marine environment with minimal anthropogenic activities. Similar findings with Abah et al. (2013) were reported *Clarias anguillaris*, had As ranged from $0.05 \pm 0.01 \sim 0.15 \pm 0.04$ µg/g in river Okpokwu, Apa in Nigeria. One of the hazardous metals with no recognized biological significance to humans is cadmium (Tchounwou et al., 2012). The main harmful consequence of cadmium is kidney poisoning, while occupationally exposed people have also reported skeletal abnormalities, lung damage, including the development of lung cancers. Although cadmium is generally poorly absorbed by the body, once it is, it is slowly eliminated, much like other metals, and builds up in the kidneys where it damages the kidneys.

3.6. Health Risk Assessment for Fish Consumption

The EDI values for As ranged from 0.19×10^{-9} (*Rhizoprionodon acutus*) to 8×10^{-9} (*Sardinella maderensis*), Hg ranged from 0.07×10^{-9} (*Penaeus notialis*) to 2.57×10^{-9} (*Sardinella maderensis*), Cd ranged from 0.12×10^{-9} (*Pagellus ehrenbergi*) to 1.45×10^{-8} (*Galeoides decadactylus*) and Pb ranged from 0.05×10^{-8} (*Pseudotolithus elongatus*) to 3.13×10^{-8} (*Galeoides decadactylus*).

The estimated THQ, HI and TCR of heavy metals/metalloid in demersal marine fish species are shown in Table 3. The THQ values in demersal marine fish species from the western off Nigeria coast ranged from 0.01×10^{-5} to 8.99×10^{-5}. The highest HI value was observed in *Pseudotolithus senegalensis* with 13.1×10^{-5} and lowest was *Rhizoprionodon acutus* with 0.43×10^{-5} which fell within the recommended threshold dose of 1. The highest TCR values for Pb and Cd were observed in *Galeoides decadactylus* with 28.2×10^{-11} and 8.70×10^{-9}, the least for Pb in *Penaeus notialis* had value of 0.01×10^{-11}, and Cd in *Rhizoprionodon acutus* had value of 0.12×10^{-9}. The results of THQ and HI of metals/metalloids were below the recommended threshold dose of 1 which implies that consumption of demersal marine fish species from the western Nigeria offshore would not pose any non-carcinogenic harmful effect on humans, although the continuous bioaccumulation of Cd in the muscle might present an acute non-carcinogenic health implycation to consumers over a period time. These findings also cor-

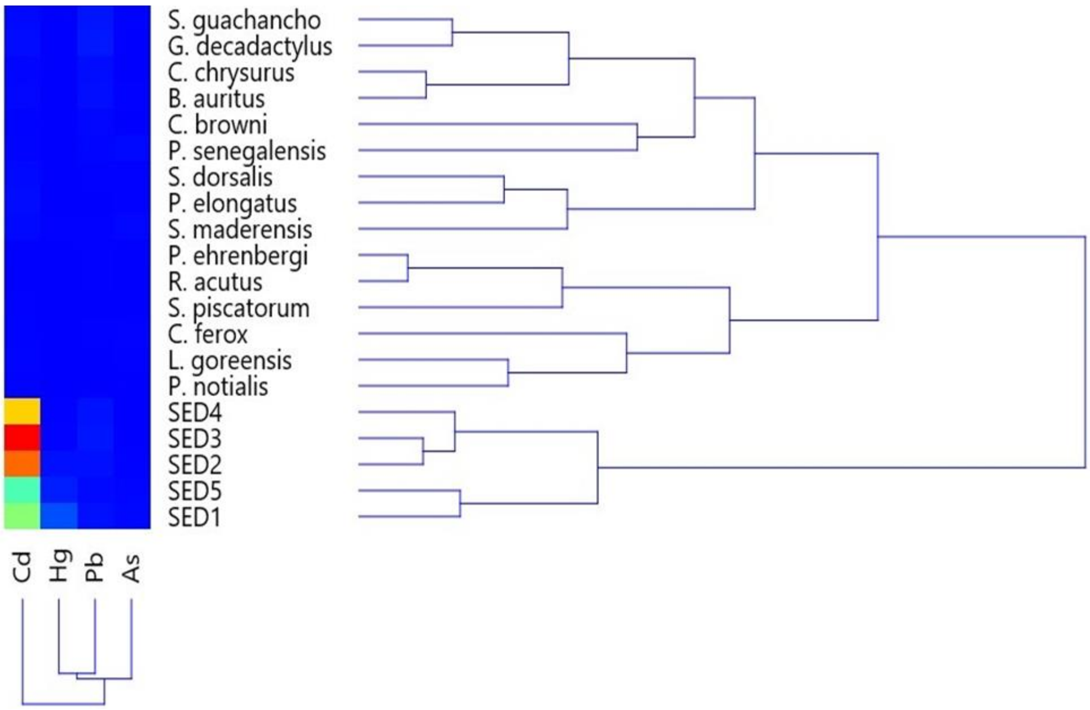


Figure 6. Hierarchical cluster analysis using Bray-Curtis Similarity Indices of heavy metals/metalloid and stations for sediment.

roborated with the study of Amirah et al. (2013) that reported the THQ of Pb and Cd were generally less than 1, and consumers would not experience significant health risk from the consumption of individual metals through contaminated fish from the selected river in Kuantan, Pahang, Malaysia. The TCR of Cd and Pb in the fish species were below the regulation range of 1.0×10^{-6} to 1.0×10^{-4} set by the USEPA (2011) which implies consumption of fish species by humans (adults) will not pose any cancer risk.

3.7. Cluster Analysis

This hierarchical cluster analysis using Bray-Curtis similarity index which reflects the correlations between the heavy metals/metalloids in sediment across the sampling stations and demersal fish species with similar source and characteristics of heavy metal contamination are presented in the dendrogram (Figure 6). Cluster 1 (C1) showed significant Cd accumulation in the sediment at station 2, 3 and 4; cluster 2 (C2) showed similar characteristics of the heavy metals/metalloids (Hg, Pb and As) across the stations with significantly low bioaccumulation in the demersal fish species at the western offshore Nigeria, Gulf of Guinea. Sultana et al. (2022) reported heavy metals in Cultured Shrimp and Aquaculture Sludge with two clusters, C1 were grouped as As, Cd and Hg, and C2 were grouped as Zn, Mn, Pb, Cr and Cu. These results indicate that the sources of Cd, As and Hg possess the same characteristics and mutual interrelations which also corroborated the present findings.

The levels of heavy metals/metalloids, HI, and THQ from sediment and demersal fish species were below 1 which proves that there are no adverse health effects to humans. To achieve sustainable development, routine periodic research to monitor the environmental activities is essential, regardless of the low contamination indication of heavy metals/metalloid in sediment and fish species within the western offshore Nigeria, Gulf of Guinea.

4. Conclusions

The study of heavy metals/metalloids in sediment and demersal fish species from western Nigeria offshore environment were generally below the sediment quality guidelines and FAO/WHO permissible limits. The applied ecological and health risk assessment indices to elucidate the pollution status of the western Nigeria offshore, Gulf of Guinea clearly established low potential adverse effect on demersal marine fish species due to the overall low ecological severity risk associated with heavy metals/metalloids in sediment. Hence, consumers of fisheries resources from western off Nigeria coast are relatively safe from being exposed to any non-carcinogenic and carcinogenic health risk.

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