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Heavy metal concentration and public health risk in consuming *Sardinella maderensis* (Sardine), *Sarotherodon melanotheron* (Tilapia), and *Liza falicipinis* (Mullet) harvested from Bonny River, Nigeria

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Contamination of the river by oil spill had put the health of the people who consume fish at risk. Five fish samples each of *Liza falicipinis* (Mullet), *Sarotherodon melanotheron* (Tilapia) and *Sardinella maderensis* (Sardine) (n=15) were collected monthly from the Bonny Estuary from February to July 2018. The samples were oven dried at 100°C and analyzed using Atomic Absorption Spectrophotometer (Model pm ver 2.02 Avanta) to determine the concentration of Zinc (Zn), Lead (Pb), Copper (Cu), Cadmium (Cd), Nickel (Ni), Chromium (Cr), Vanadium (V) and Mercury (Hg). The result show that there is significant difference ($F7, 130 = 65.6$, $P < 0.0001$) in heavy metal concentration in the three fish species. Zinc had the highest concentration followed by Lead, Copper, Nickel and Cadmium. There was no seasonal difference ($F1, 136 = 1.58$, $P > 0.05$), although dry season had higher concentration. Sardine had the highest concentration of heavy metal followed by tilapia and mullet. Result of EDI indicates higher intake during the dry season (that is February). Highest EDI was recorded in tilapia (5673.1 ± 5632.5 mg/kg). Similarly, highest Cd, Cu, Cr, Ni and Zn were recorded in sardine whereas Pb was highest in tilapia. Mullet had highest daily intake for February and March. Sardine had the highest THQ for Cd, Cu, Cr, Ni and Zn, whereas tilapia had high values in Cd and Ni while mullet had high values in Pb. The implication of this result is that dry season is not the best time to consume these three fish species.

Key words: Heavy metals, bioaccumulation, Niger Delta, Bonny Estuary, fishes, food chain.

INTRODUCTION

Studies have shown that despite the health benefit of deriving protein from consuming fish, human health can be compromised if heavy metals such as Lead, Cadmium, Arsenic, and Mercury are present (Bosch et al., 2016). Furthermore, concentration of heavy metals varied significantly between species and organs, and mercury was found to accumulate more in the muscle (Farkas et al., 2000; Cai et al., 2019). Lead and Nickel were shown to cause the greatest risk to health, while tilapia species had no risk of consumption (Taweel et al., 2013). Heavy metal pollution in the aquatic ecosystem has long been recognized as a serious environmental

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concern. Anthropogenic activities such as oil exploration and exploitation, discharge of municipal and industrial wastes into the aquatic environment are major sources of pollution. These heavy metals may accumulate in the tissues of marine organisms and are transferred to humans through consumption (Ali and Khan, 2019)

Some metals (copper, iron and zinc) at low concentrations are of nutritional importance and are essential for healthy living; in contrast, metals such as Mercury, Cadmuim and Lead have not been known to play beneficial role in human metabolism and are considered as chemical carcinogens even at very low levels of exposure (Luch, 2005). Generally, heavy metals which are present in the environment in minute concentrations become part of various food chains through biomagnifications; leading to concentration increase to a level that may prove toxic to both humans and other living organisms. Dietary is the main route of human exposure to heavy metals except for occupational exposures (Moslen and Miebaka, 2016).

Fish are excellent source of protein and its low – calorific value makes it a healthier alternative to red meats or poultry; it is also rich in omega-3 polyunsaturated fat which has been known to reduce cholesterol levels in man (Kaushik and Seiliez, 2010 **).**

The Bonny Estuary in the Niger Delta region empties directly into the Atlantic Ocean at Bonny Island. Bonny is the host to the Liquified Natural Gas (LNG) Company, which utilizes the gas flared during crude oil exploration to produce methane, a cooking gas. In this operation crude oil is spilled into the river and contaminates the drinking water source leading to proliferation of water borne diseases and food poisoning. Gas and exhausts flared into the atmosphere cause soot, which lead to respiratory diseases such asthma, bronchitis, cough, and catarrh. Large scale oil and gas production, transportation, industrialization are the order of the day in this location leading to cases of oil spills, gas flares, industrial discharges, agricultural runoff and domestic effluents (Babatunde et al., 2019; Numbere, 2018). Despite these activities, artisanal fisheries in the estuary largely support the livelihood of its inhabitants who have little or no knowledge of the extent of pollution in the estuary.

For riverine communities such as the inhabitants of the study area, seafood is being served at almost every meal. Fish is consumed either freshly prepared or smoked. Shellfish, especially *Tympanotonus fuscatus* are used largely as a condiment in most meals eaten in the Niger Delta (Gomna and Rana, 2007). Therefore, it is expedient to determine the concentrations of heavy metals in this seafood in order to ascertain the potential health risk consumers may face.

Heavy metals are non-biodegradable, inorganic chemicals that tend to accumulate overtime in the bodies of organisms due to inability to metabolize them. Thus, it is important to determine the heavy metal concentrations in seafood in order to evaluate the impact of these metals on the health of the consumers. In Nigeria, most studies on metal accumulation in edible biota have failed to consider the risk associated with exposure through the food chain. However, few works have been reported on the health risk associated with the consumption of certain seafood and vegetables in Nigeria. Fernandez et al. (1999) reported that there is a cancer risk associated with eating contaminated fish. Similarly, Moslen and Miebaka (2017) reported on negligible health risk associated with consumption of tilapia (*Sarotherodon melanotheron***)** harvested from Azuabie creek, upper Bonny estuary. There are limited data on health risk assessment with regards to heavy metal level and consumption of fish species *Liza falicipinis*, *Sarotherodon melanotheron* and *Sardinella maderensis* harvested from the Bonny Estuary (River). The objectives of the study therefore, are: (1) To determine the heavy metal concentrations in three fish species; (2) To compare the heavy metal concentration in dry (February-March) and wet (April-July) seasons; (3) To determine the month with the highest heavy metal concentration, and (4) To determine the health risk assessment in consuming the fishes.

MATERIALS AND METHODS

Study area

The Niger Delta of Nigeria is situated in the Gulf of Guinea between latitudes 3° and 5° N and longitudes 5° and 8° E. It is the largest delta in Africa with an area of about 70,000 km^2; it is rich in biodiversity and maintains the largest drainage system into the Atlantic Ocean in West Africa (Akpomuvie, 2011). The sampling site is Bonny River located in the Niger Delta area of Nigeria. It is a 127 km long tidal estuary and lies on the eastern flank of the Niger Delta between latitudes 4.25° and 4.50° N and longitudes 7.00° and 7.15° E (Figure 1). It is a place of residence and fishing activities by local inhabitants.

Research design

Five fish samples each of *Liza falicipinis* (Mullet), *Sarotherodon melanotheron* (Tilapia) and *Sardinella maderensis* (Sardine) (n=15) were collected monthly for six months, that is February 2018 to July, 2018 from artisanal fishermen along the Bonny Estuary Samples were preserved in an ice box and transported immediately to the laboratory for analysis (Figure 2).

Sample collection and preparation

Each fish sample was placed on a petri dish and properly washed with distilled water and labeled. The samples were oven dried at 100°C to ensure that all the water content were removed to get a constant weight. Each sample was homogenized using clean mortar and pestle. Thereafter, 3.0 g of each sample were weighed. 20 ml of aqua regia prepared by mixing 30 ml of 10% hydrochloric acid and 70 ml of 10% Trioxonitrate (V) acid (HNO_3) were added and digested in a water bath. 10 ml of de-ionized water was added to the content of each flask and was allowed to cool. The content of each flask was later filtered with Whatman 0.05 μm filter paper.

The salinity, temperature, conductivity, TDS and pH of the four sample sites along the Bonny Estuary was taken in-situ whereas for the DO, the water sample was collected using amber colored bottle

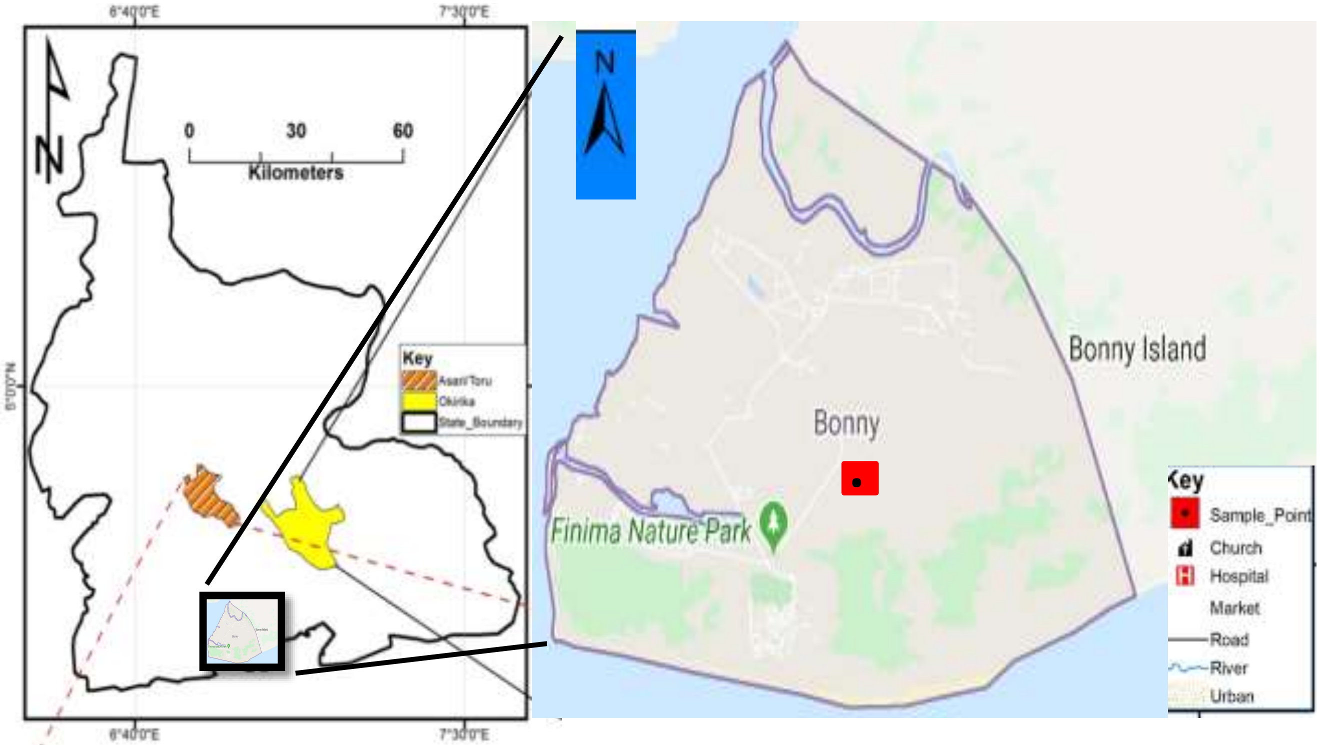

Figure 1. Map of sample location, Bonny Niger Delta Nigeria.

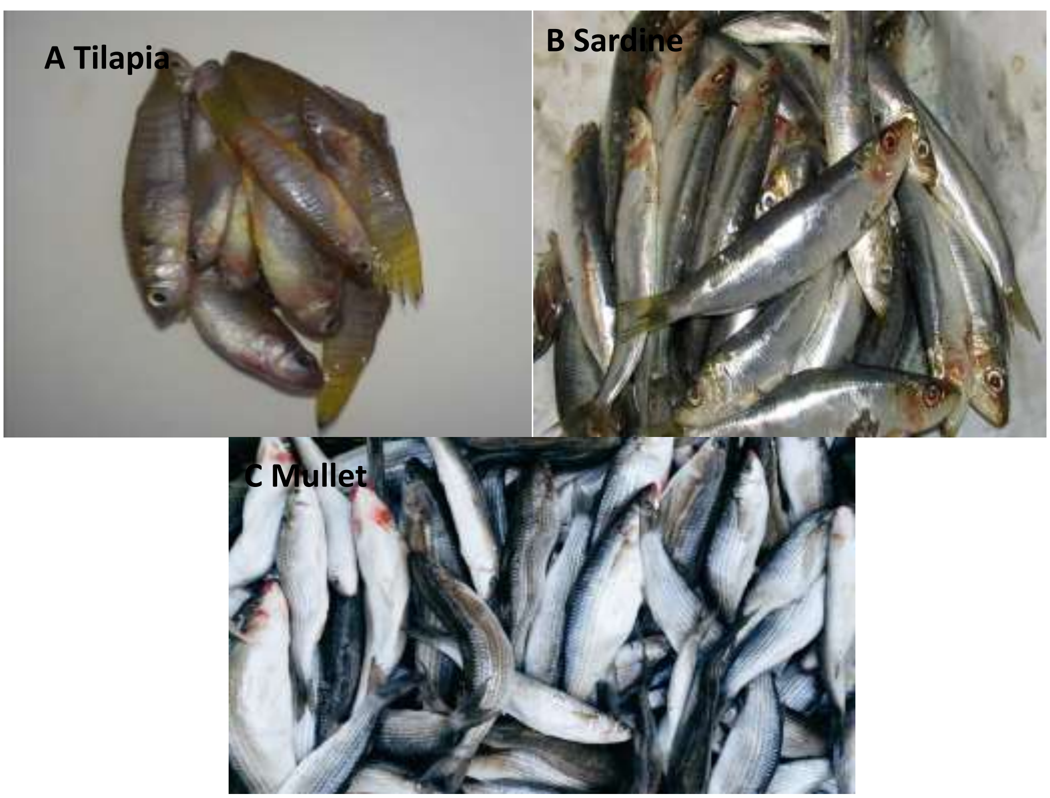

Figure 2. Three different fish samples (A) Tilapia, (B) Sardine and (C) Mullet collected from Bonny Rivers, a Niger Delta Nigeria.

Table 1. Reference dose of heavy metals in food.

Metal	Reference dose (mg/kg/day)
Pb	0.004
Cd	0.001
Zn	0.3
Ni	0.02
Cr	0.002
Hg	0.001
V	0.001
Cu	0.001

Source: USEPA (2011b); Uche et al. (2017); Moslen and Miebaka (2017).

and was determined by the Modified Azide or Winkler's method (APHA, 1985). To a 70 ml BOD bottle filled with 0.5 ml manganese sulphate (Winkler I) and 0.5 ml Alkali-iodide-azide reagent (Winkler II) were added. After about 10 min, 0.5 ml concentration H_2SO_4 was added, re-stoppered and mixed for complete dissolution of precipitate. A 50 ml portion was placed in an Erlenmeyer flask, five drops of freshly prepared starch solution added and titrated with 0.025N $Na_2S_2O_3$ (Sodium thiosulphate) solution. The titration was continued to the first disappearance of the blue color.

DO mg/L was calculated using: $\frac{V \times N \times 8000}{ml\ sample}$

Where V is the volume in ml and N is the normality of sodium thiosulphate solution used in titration.

Laboratory analysis

Heavy metals determination in sample was then performed using Atomic Absorption Spectrophotometer (Model pm ver 2.02 Avanta). The analysis of the standard, reagent blanks and replicates were run in the same way and concentrations determined using standard solutions prepared in the same acid matrix. For each of the metals under study, atomic absorption spectrophotometer (model pm ver 2.02 Avanta) was calibrated using standard of the metals. Metals of interest are: Zinc (Zn), Lead (Pb), Copper (Cu), Cadmium (Cd), Nickel (Ni), Chromium (Cr), Vanadium (V) and Mercury (Hg).

Human health risk assessment

The values of fish metal accumulation and constants were used to calculate the estimateddaily intake of metals (EDI), chronic daily intake for the metals (CDI), target hazard quotients (THQ) and Hazard quotient (HI). The calculations were based on the standard assumption for integrate USEPA risk analysis, FDA, and USDOE standard.

Estimated daily intake (EDI) of heavy metals

EDI is the estimated daily intake of metal concentration in the fish expressed in mg kg^{-1}. Calculations were made based on the standard assumption from USEPA-IRIS (2016), considering the Ingestion rate for fish to be 0.10 kg/fish person/day and an adult average body weight of 70 kg as reported by Moslen and Miebaka (2017).

$$\mathrm{EDI(kg/day)} = \frac{C_{\mathrm{metal}} \times \mathrm{IFR}}{BW \times 0.01}$$ (USEPA, 2011a)

Where: C_{metal}= the metal concentration in fish (mg/kg); IFR = Ingestion rate for fish (0.10 kg/day); BW = Average body weight (70 kg).

Target hazard quotient (THQ)

The non-carcinogenic fish ingestion equation is as follows:

$$\mathrm{THQ} = \frac{\mathrm{Efr \times ED \times IFR \times C \times 0.001}}{\mathrm{RfD \times BW \times ATn}}$$

Where: Efr = Exposure frequency in 365 days/year; ED = Exposure duration in 55 years (Life expectancy for Nigeria) (Uche et al., 2017); IFR = Ingestion rate for fish (0.031 kg /day); C = Concentration of metal in food sample in mg/kg; RfD = Reference oral dose of metals during a life time (Uche et al. 2017; Mahmoud and Abdel-Mohsein, 2015); ATn = (ED x EF) = 20, 075 averaging time for non-carcinogens (Wang et al., 2005); BW = Average body weight is 70 kg.

RfD is an estimate of a daily oral exposure for human population, which is a non-carcinogenic effect during a lifetime; generally used in EPA's non-cancer health assessment (Uche et al., 2017; Table 1).

Target hazard quotient

The human health risks from consumption of fish by the populace were assessed using the target hazard quotient (THQ). It is defined as the ratio between estimated daily intake (EDI) and reference oral dose (RfD). THQ is used to express the risk of non-carcinogenic effects (Yu-Jun et al., 2011). If the ratio is equal to or greater than 1, an exposed population experiences health risks.

$$\mathrm{THQ} = \frac{\mathrm{EDI}}{\mathrm{RfD}}$$

Where: EDI= Estimated daily intake for the toxicant (mg/kg-day); and RfD =chronic reference dose for the toxicant (mg/kg-day).

Although the THQ-based assessment method does not provide a quantitative estimate for the probability of an exposed population experiencing a reverse health effect, it does, however, provide an indication of risk level due to exposure to pollutants (Guerra et al., 2012; Mahmoud and Abdel-Mohsein, 2015). The THQ has been recognized as a useful parameter for evaluating risk associated with consumption of metal-contaminated fish (USEPA, 2011a).

Hazard index (HI)

Hazard Index (HI) is used to evaluate the potential risk to humans

Table 2. Mean and standard error of physico-chemical parameters for different stations at the Bonny River Niger Delta, Nigeria.

Parameter	Stations			
	1	2	3	4
	(Mean± SE)	Mean ± SE	Mean ± SE	Mean ± SE
pH	7.43±0.05	8.22±0.06	8.89±0.05	7.05±0.07
Temperature (^{0}C)	29.14±0.23	27.45±0.27	29.75±0.29	28.34±0.21
Salinity ($^0/_{00}$)	13.13±0.12	11.56±0.14	12.67±0.11	15.86±0.14
DO (mg/L)	2.88±0.35	5.34±0.11	5.19±0.05	6.47±0.23
TDS (mg/L)	15.34±0.34	12.89±0.46	16.65±0.43	14.16±0.48
Conductivity	27.32±0.12	23.65±0.18	20.98±0.23	21.47±0.15

when several heavy metals are involved (USEPA, 1989). Hazard index is calculated as the total sum of hazard quotients (HQ). Since different pollutants can result to similar negative health effects hence a combination of hazard quotients linked with different substances is necessary. When a hazard index is <1.0 it indicates that there is no negative health effect. It was calculated using the formula below:

HI = ΣTHQ (THQPb + THQCd + THQCr +THQCu…+ THQZn) (USEPA, 2011)

Statistical analysis

An analysis of variance (ANOVA) was conducted since there were multiple samples (n=15) and monthly replications to determine whether there was a significant difference in heavy metal concentration for the three fishes (tilapia, mullet and sardine). The data was first log transformed to ensure that they were normal and the variances were equal. Bar graphs were then used to illustrate the significance and difference in concentration in the fish species. All analyses were done in R (R Development Core Team, 2014). Tukey HSD test was then done to determine where the significance lies (Logan, 2010).

RESULTS

Physico-chemistry of study area

The temperature of the study area range between 27 and 30˚C. The dissolved oxygen ranges between 2 and 6 mg/L. The total dissolved solid (TDS) ranges between 11.56 and 15.86mg/L and the conductivity ranges between 20.98 and 27.32 µohm/cm (Table 2).

Heavy metal concentration in three fish species

The result (Figure 3) indicates that there is significant difference ($F_{7,\ 130}$ = 65.6, P < 0.0001) in the concentration of heavy metals in *Sardinella maderensis* (Sardine), *Sarotherodon melanotheron* (Tilapia), and *Liza falicipinis* (Mullet). Zinc has the highest overall concentration followed by Lead, Copper, Nickel and Cadmium. This is in line with results of Anaero-Nweke et al. (2018) who showed that Zinc concentration was highest in gill, muscle and liver of *S. melanotheron*. Similarly, Numbere, (2019) revealed that Zinc concentration was highest in the body parts of crab *Goniopsis pelii*. Zinc, Copper and Cadmium concentrations were highest in sardine as compared to tilapia and mullet. Lead on the other hand, had the highest concentration in mullet followed by sardine and tilapia. Nickel concentration was highest in tilapia. However, Vanadium, Mercury and Chromium showed no trace amount in all the fish species sampled (Figure 3).

Heavy metal concentration in three fish species in dry and wet seasons

There was no significant difference in heavy metal concentration in the three fish species in wet and dry season ($F_{1,\ 136}$ = 1.58, P >0.05; Figure 4). However, sardine had the highest concentration of heavy metal followed by tilapia and mullet in both dry and wet seasons. The order of heavy metal concentration in fish sample is sardine>tilapia>mullet.

Monthly heavy metal concentration in three fish species

Heavy metal concentration in sardine was the highest for each month apart from March, where tilapia was slightly higher than other species. However, the ANOVA result (Figure 5) indicates that there is no significant difference ($F_{5,\ 132}$ = 0.4, P > 0.05) in heavy metal concentration across months.

Human health risk assessment

Estimated daily intake (EDI)

Table 3 indicates the calculation of the cumulative intake of heavy metal by fish species. The EDI result indicates that there was higher intake of heavy metal by fish

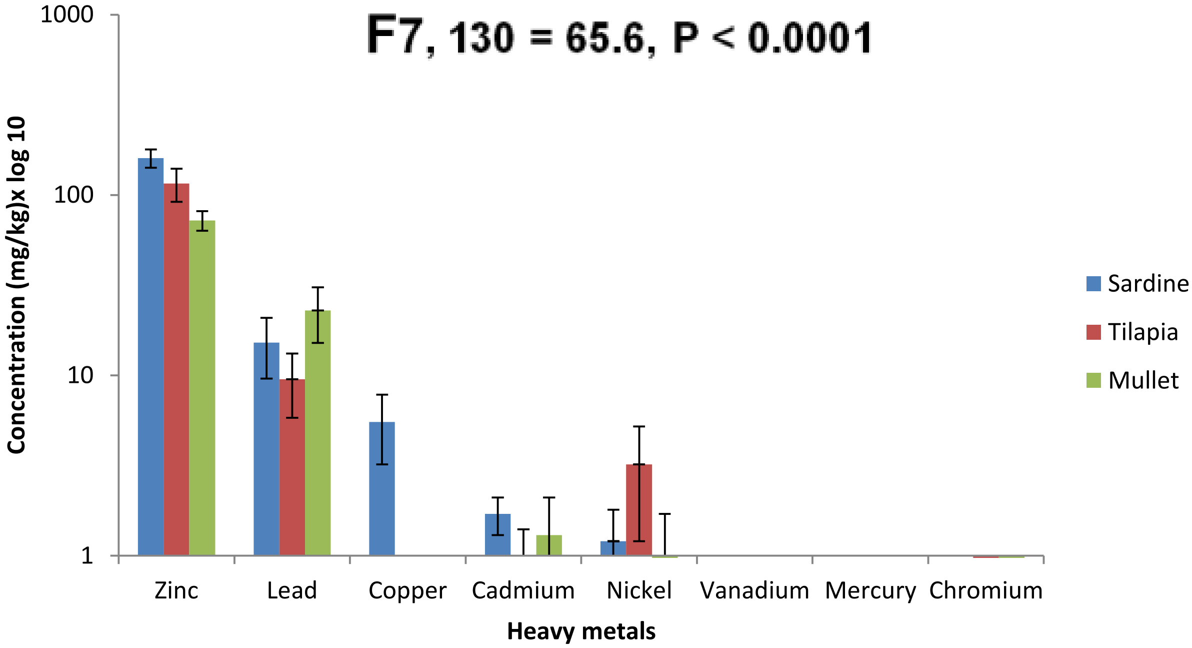

Figure 3. Concentration of heavy metals in three fish species (that is, sardine, tilapia and mullet) harvested in Bonny River, Niger Delta, Nigeria. Vertical lines show ±1 standard error of the mean.

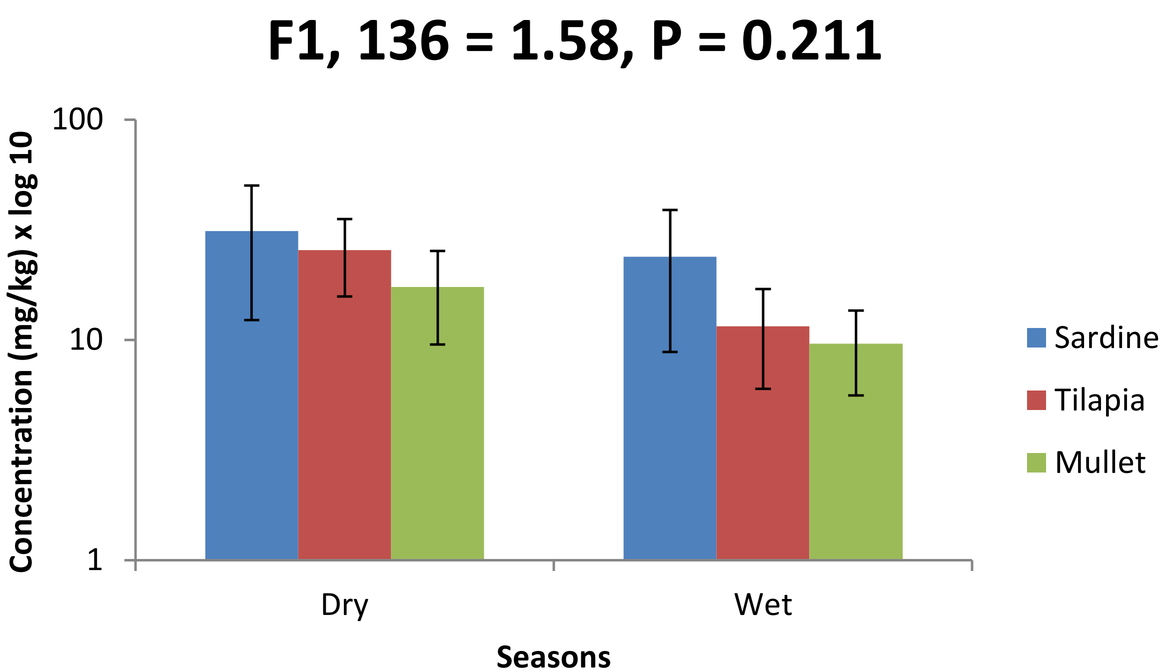

Figure 4. Heavy metal concentration in three fish species (sardine, tilapia and mullet) in dry and wet seasons in Bonny River, Niger Delta, Nigeria. Both seasons show no statistical significant difference (P > 0.05) in heavy metal concentration. Vertical lines show ±1 standard error of the mean.

species during the dry season than during the wet season (Table 3). Highest EDI was recorded in tilapia (5673.1 ± 5632.5 mg/kg). Similarly, Table 4 shows the estimated daily intake of individual heavy metals (that is, Cd, Cu, Cr, Pb, Hg, Ni, V and Zn) by the three fish species sampled at the Bonny River. Furthermore, highest Cd, Cu, Cr, Ni and Zn were recorded in sardine (Table 3) whereas Pb was highest in tilapia. The order of

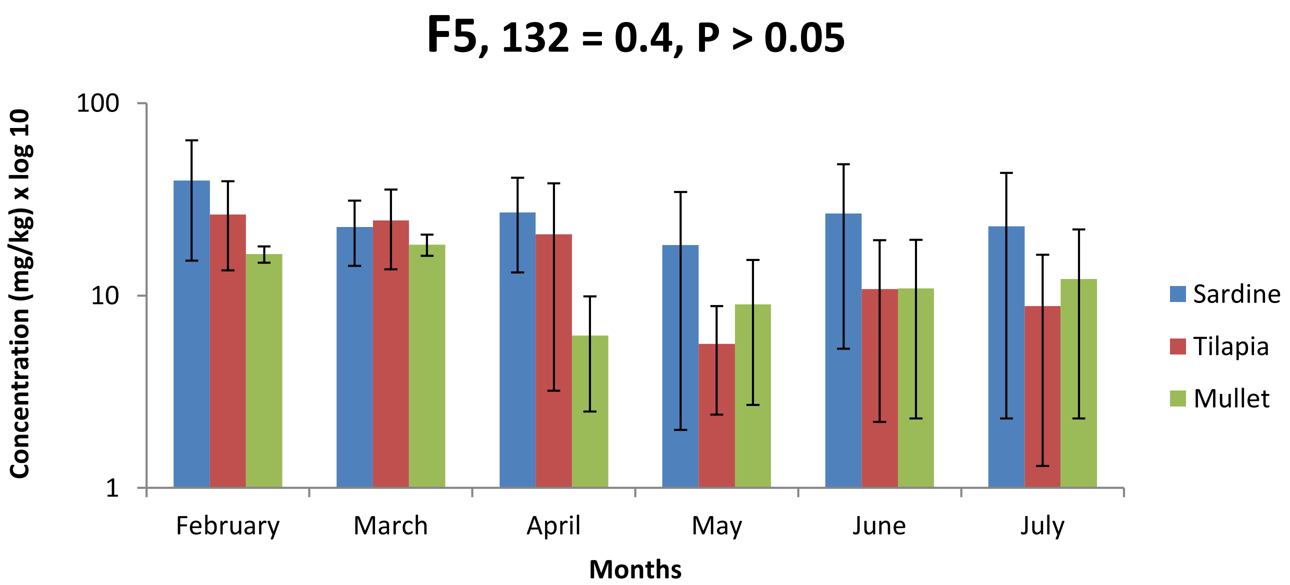

Figure 5. Monthly heavy metal concentration in three fish species harvested in Bonny River, Niger Delta, Nigeria.

Table 3. Monthly estimated daily intake (EDI) of cumulative heavy metals per month by three species of fishes from the Bonny River, Niger Delta Nigeria from February to July, 2018.

Species	Months					
	February	March	April	May	June	July
Sardine	47.1 ± 46.4	44.1 ± 43.6	33.45 ± 31.9	15.1 ± 14.6	29.4 ± 28.8	28.1 ± 27.5
Tilapia	5673.1 ± 5632.5	32.7 ± 32.2	27.9 ± 26.8	8.1 ± 8.0	16.2 ± 16.1	12.9 ± 12.8
Mullet	15.9 ± 15.5	18.0 ± 17.7	8.8 ± 8.7	9.0 ± 8.9	13.1 ± 13.0	18.1 ± 18.0

Table 4. Estimated daily intake of individual heavy metals by three species of fishes from the Bonny River, Niger Delta Nigeria.

Species	Metals (mg/l)							
	Cadmium	Copper	Chromium	Lead	Mercury	Nickel	Vanadium	Zinc
Sardine	0.5 ± 0.2	1.7 ± 0.7	0.4 ± 0.2	0.7 ± 0.1	0	1.7 ± 0.9	0	258.0 ± 40.0
Tilapia	0.03 ± 0.02	0.0 ± 0.0	0.04 ± 0.03	7518.3± 7516.3	0	1.1 ± 0.7	0	175.1 ± 36.3
Mullet	0.04 ± 0.03	0.0 ± 0.0	0.04 ± 0.02	0.9 ± 0.2	0	0.3 ± 0.3	0	109.3 ± 13.6

daily intake of heavy metal in fish samples is sardine>tilapia>mullet.

Target hazard quotient (THQ)

Higher THQ was obtained during the dry season (Table 5). Mullet had highest daily intake for February and March. Sardine has the highest THQ for Cd, Cu, Cr, Ni and Zn, whereas tilapia had high values in Cd and Ni while mullet had high values in Pb (Table 6). The order of hazard for fish samples is sardine>tilapia>mullet

DISCUSSION

Aquatic organisms such as fishes are susceptible to heavy metal contamination through body contact or filter feeding. These heavy metals bioaccumulate in their tissues and organs (Farkas et al., 2000; Cai et al., 2019) and are later transferred to humans who consume them thereby posing as danger to their health (Taweel et al., 2013). The disposal of waste into water bodies, and spillages from oil and gas explorations are some of the causes of increased pollution of rivers. The liquefied natural gas (LNG) situated in Bonny is being supplied by

Table 5. Monthly target hazard quotient (THQ) of three fish species harvested from the Bonny River, Niger Delta Nigeria from February to July, 2018.

Species	Months					
	February	**March**	**April**	**May**	**June**	**July**
Sardine	0.06 ± 0.03	0.05 ± 0.03	0.02 ± 0.01	0.01 ± 0.006	0.1 ± 0.09	0.01 ± 0.008
Tilapia	0.08 ± 0.04	0.08 ± 0.04	0.07 ± 0.04	0.01 ± 0.006	0.01 ± 0.007	0.01 ± 0.007
Mullet	0.1±0.07	0.1 ± 0.08	0.01 ± 0.001	0.06 ± 0.04	0.05 ± 0.03	0.02 ± 0.009

Table 6. Target hazard quotient (THQ) of metal in three fish species harvested from the Bonny River, Niger Delta Nigeria.

Species	Metal (mg/l)								
	Cadmium	**Copper**	**Chromium**	**Lead**	**Mercury**	**Nickel**	**Vanadium**	**Zinc**	**HI**
Sardine	0.03 ± 0.01[a]	0.004 ± 0.002[a]	2.4×10^{-5} ±1.2[a]	0.1 ± 0.05	0	0.01 ± 0.005[a]	0	0.2 ± 0.1[a]	0
Tilapia	0.03 ± 0.02[a]	0	1.6×10^{-5} ± 1.5	0.1 ± 0.04	0	0.01 ± 0.003[a]	0	0.06 ± 0.01	0.2 ± 0.1
Mullet	0.04 ± 0.03	0	2.4×10^{-6} ±1.2	0.2 ± 0.07[a]	0	0.002 ± 0.001	0	0.04 ± 0.01	0.3 ± 0.1[a]

numerous pipelines from the Port Harcourt Refinery. Part of this pipelines run offshore through the swamps, and serve as entry points of pollutants into the aquatic environment. High zinc concentration has been reported in studies of fish (Eremasi et al., 2018). Zinc concentration is often high in the waters and coastal zones of the Niger Delta (Figure 3) because of its multiple entry points such as through the earth crust along mangrove forest and as corrosion products from metallic substances used as alloys for pipelines. However, Zinc at low concentration is of nutritional importance. Cadmium on the other hand, is toxic and carcinogenic at low concentration (Duruibe et al., 2007). Cadmium when released to the environment can lead to the outright death of fishes or can bioaccumulate in their bodies, and is later transferred to humans who consume them. Sardine species were found to have higher concentration of heavy metal probably because of their scale less body which leads to more diffusion of metallic substances from the aquatic environment into their bodies. Nevertheless, the three most harmful metals of Vanadium, Mercury and Chromium were not found in the bodies of fishes sampled. These metals are very toxic, that is, they have carcinogenic and teratogenic effect on humans (Saxena et al., 2020). Mercury, which is one of the most harmful metals, can cause genetic abnormalities in new born babies if consumed by pregnant mothers. It can also cause brain damage and mental disorders if consumed via sea food (e.g. fishes, periwinkles, crabs etc).

This study shows that seasons have effect on heavy metal concentration in aquatic media and aquatic organisms. This is in line with studies of Farkas et al. (2000) that revealed higher Cd concentration in eel fish in autumn season. Autumn weather in temperate region is similar to dry season in the Niger Delta area of Nigeria. There is a concentrating effect of dryness (Figure 4), which tends to increase heavy metal concentrations in waters and within organisms that reside in them. The result shows that the consumption of fishes during the dry season is riskier than during the wet season. Although statistically, the result is not significant, but physiological effect is not controlled by statistical significance, because minute concentration can have magnified effects in the body. In the same vein, although there is no significant difference in terms of season, dry season was shown to have slightly higher concentration (Figure 4). Dryness of the environment causes high evaporation from the river surface leading to increase in heavy metal concentration. February, which is a dry season month, had the highest concentration of heavy metal in sardine (Figure 5). All the results for heavy metal and health risk analysis had revealed that sardine should be thoroughly monitored because of its ability to accumulate high heavy metal concentration before being sold to the public for consumption. Previous studies had indicated that dry season has a higher intake (EDI) of heavy metals by fishes (Miebaka and Moslen, 2016). This thus predispose the fishes to bioaccumulating more heavy metals. This makes the fishes to be risky to human health if consumed.

The result indicate that consumption of the three fishes especially Mullet during the dry season is also hazardous to human health, However, sardine is more hazardous because of its ability to bioaccumulate high amount of heavy metals. Furthermore, sardine has the highest health risk of the three fishes sampled whereas February and March are the riskiest months to consume sardine, which are dry season and the ending of the dry season months, respectively.

CONCLUSION AND RECOMMENDATION

The implication of this result is that the total hazard quotient even though not too high may keep increasing to a harmful level that will be detrimental to the health of the public. This is because stochastic environmental change can push the concentration limit of the heavy metals in the fishes from a non-harmful to a harmful level. Therefore, residents living around the Bonny River should be careful in the way they consume sea food so as to prevent the accumulation of heavy metals in their bodies which may be too risky for their health. Furthermore, there should be constant monitoring of all sea food harvested from the Bonny Estuary. This will help to reduce heavy metal poisoning.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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