Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2022, Volume 13, Issue 04, Page 424-434

http://www.jmaterenvironsci.com

Characterization and Health Risk Evaluation of Water and Fish Samples obtained from Ogun River in Lagos, Nigeria

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Received 10 Apr 2022,
Revised 30 Apr 2022,
Accepted 30 Apr 2022

Keywords
- ✓ *Average daily exposure,*
- ✓ *Carcinogenic risk,*
- ✓ *Ecosystem services,*
- ✓ *Hazard quotient,*
- ✓ *Lead.*

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Abstract
River Ogun is a major river in southwest Nigeria that provides important ecosystem services such as agricultural production, freshwater provision, flood control, and industrial use. However, these ecosystem services pollute and degrade rivers, necessitating periodic evaluation of rivers that serve such purposes. This study characterized and assessed the health risk of water and fish samples obtained from Ogun River in Lagos, Nigeria. Samples of the water and fish were analyzed for heavy metals, namely lead, nickel, cadmium, chromium, and arsenic, using standard protocols, and the results were compared with the acceptable limits. The humans' average daily oral exposure (*ADOE*), average daily dermal exposure (*ADDE*), estimated daily intake (*EDI*), hazard quotient (*HQ*), and carcinogenic risk (*CR*) of the heavy metals were also calculated. The water and fish samples had non-tolerable concentrations of heavy metals, except for arsenic. The levels of heavy metals in fish tissues were higher than in the water, with the highest concentrations in the intestines, followed by the gills, livers, and muscles. The *ADOE*, *ADDE*, and *HQ* of heavy metals in the water samples were within the permissible limits, except for the *ADDE* of Ni and Cd. The *EDI* of the heavy metals in the fish as well as the *CR* of the heavy metals in the water and fish samples were above the permissible limits. Overall, the results suggest that the water and fish samples may not be suitable for consumption. There is a need for heavy metal remediation and control on the river.

1. Introduction
Rivers are the main sources of surface water and provide essential economic-boosting ecosystem services [1]. Recreational activities, tourism, transportation, flood control, fishing, industrial use, agriculture, natural habitats for numerous organisms, cultural services, and hydropower production are all examples of ecosystem services [2,3]. Because water is necessary for growth and development, rivers are an important determinant of human settlement [4,5].
Unfortunately, pollution threatens the services provided by rivers [6]. Waste of all forms is often dumped into rivers without treatment. The bulk of the time, even treated wastes, which are still potentially hazardous to aquatic organisms, end up in rivers [7]. Pollution compromises river water

quality and ecosystem services and reduces biodiversity [8,9]. Human populations that live near rivers and rely on them for food are affected by the loss of ecosystem services such as fishing and farming [9]. Furthermore, pollution has an impact on the health of those who drink, bathe, wash, and utilize river water for other domestic purposes [10]. The consumption of aquatic life such as fish and crabs, as well as crops and vegetables grown near polluted rivers, may also have an impact on human health [4]. Toxicants in river water can seep into surrounding groundwater recharge systems, causing health risks through ingestion, inhalation, and dermal contact [11].

Heavy metals are among the worst water contaminants [12]. Heavy metals are dense and non-biodegradable, with zinc (Zn), nickel (Ni), lead (Pb), arsenic (As), chromium (Cr), copper (Cu), and cadmium (Cd) being the most commonly detected in water [13]. Some of these heavy metals are found naturally in minute quantities in biological systems where they perform essential functions; they become harmful only at high doses [14]. As a result, continual monitoring of heavy metal levels and safety in rivers is imperative to ensure that the river continues to perform its ecosystem functions while also protecting the health of human and aquatic populations. Heavy metal level evaluations of water and aquatic life such as fish are often done by atomic absorption spectroscopy. Moreover, some standard formulas are employed to calculate the risks of toxic metals in water and aquatic life [15].

In Lagos, Nigeria, Ogun River offers important ecosystem services to several densely populated communities. Farming activities take place throughout the year along the river course, and the river also serves as the main source of water for several settlements. Locals eat the river's catch, and the river's courses are fish selling points. Unfortunately, the river receives a lot of domestic, industrial, and agricultural waste daily, which necessitates periodic monitoring of the river. This study assessed the levels and health risks of heavy metals in water and fish (*Clarias gariepinus*) obtained from the Ogun River.

2. Materials and Methods

2.1 Description of the study area

This research was conducted on Ogun River in Lagos State, Nigeria (Figure 1). Lagos is one of Africa's economic hubs and one of the world's most densely populated cities ([16] Yahaya *et al*., 2019b). The city is the most populated and industrialized in Nigeria. The climate of Lagos State is mainly wet and rain falls from March through November, with the remaining time being a dry season. The mean annual rainfall is about 950mm, and temperatures range between 24 °C and 39 °C ([17] Ipaye and Ogunbajo, 2020). The vegetation of the state is mainly tropical.

The Ogun River has its watershed in Oyo State and flows through several communities in Ogun and Lagos States before finally draining into the Lagos Lagoon through Mile 12 and Ikorodu areas of Lagos State. The river serves vital domestic, economic, and ecological functions for the communities that have settled along its course. However, an enormous amount of domestic, industrial, municipal, and agricultural waste is discharged into the river, which could have compromised the water quality of the river and thus its function. This necessitates periodic monitoring of the river to safeguard human health and ensure the river continues to deliver its functions.

2.2 Sample collection and preparation

Water samples were obtained from Ogun River between March and June 2021. The sampling was done randomly on the surface and bottom of the river's bank and middle at different times of the day. The water samples were collected in disinfected plastic wares, tightly sealed, and kept in a refrigerator at 4 °C in the laboratory. Similarly, mature *C. gariepinus* were caught from the river and carried in wellaerated material with water from the river. The gills, livers, intestines, and muscles of the fish were collected and dried under shade for 7 days, and later dried to a constant weight in the oven at 80 °C. A laboratory grinder was used to grind the fish samples into powder, homogenized, and put in a desiccator to maintain their dryness.

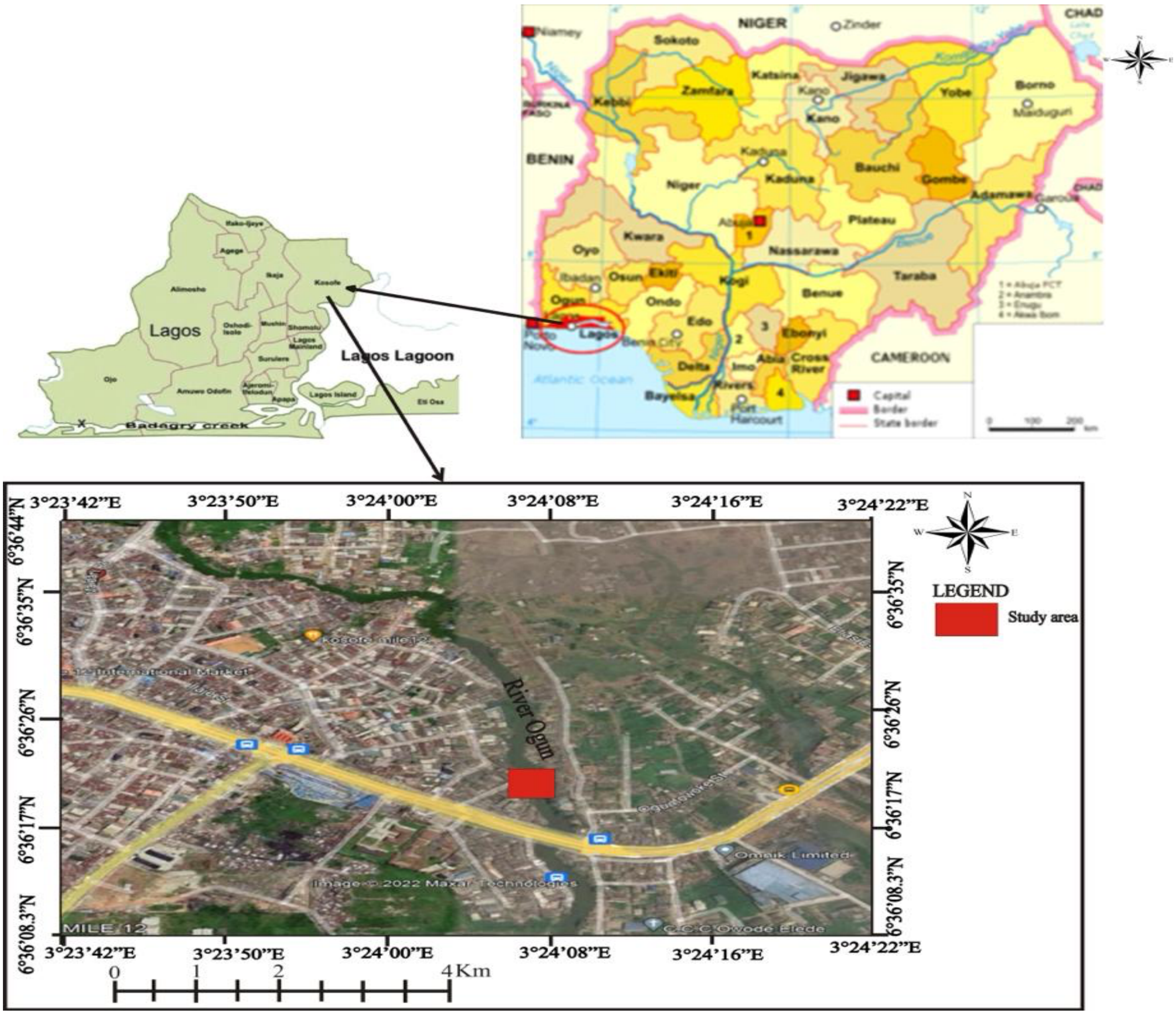

Figure 1: Location of the Study Area

2.3 Heavy metal analysis

The sample digestion was done by transferring 10 ml of concentrated H_2SO_4 to 100 ml of each water sample and 1 g of powder from each fish tissue sample and heating them in a water bath. The digestion was done gradually, with an increasing temperature from 80 °C to between 150 and 250 °C, and took about an hour, as indicated by the appearance of white fumes. The mixture was left to cool and then poured into a 50-ml beaker and topped off to the meniscus with distilled water. The solution was transferred to a plastic bottle, labeled, and the levels of chromium (Cr), lead (Pb), cadmium (Cd), nickel (Ni), and arsenic (As) were evaluated using a UNICAM atomic absorption spectrophotometer (model 969).

2.4 Quality assurance and control

All the reagents used were formulated from pure analytical-grade chemicals. Glass and plastic materials used during the analyses were washed and rinsed thoroughly. The items were then disinfected with 10% concentrated HNO_3 and cleansed with distilled water. The accuracy of the analyses was ensured by checking for the background contamination of the samples, in which blank samples were analyzed after every five analyses. Furthermore, each sample was analyzed thrice, and the accuracy of the values was 95%. As a result, the mean value of the three analyses was used for further assessment.

2.5 Health risk assessment of the water samples

The cancerous and non-cancerous risks of daily intake of heavy metals in water were calculated from equations 1-4 [15].

$$ADOE = \frac{C \ x \ IR \ x \ ED \ x \ EF}{ABW \ x \ AT} \quad (1)$$

From equation 1: *ADOE* means average daily oral exposure to heavy metals (mg/kg/day) in water; *C* represents the concentration (mg/l) of each heavy metal; *IR* indicates intake rate (2L/day) of water; *ED* stands for exposure duration (equivalent to the life expectancy of a resident Nigerian = 55); *EF* is the exposure frequency to contaminants (which is equal to 365 days/year); *ABW* denotes the average body weight (equivalent to the average body weight of resident Nigerians = 65kg); *AT* is the average time (obtained from the product of *Ed* x *Ef* = 20075).

$$ADDE = \frac{C \ x \ SA \ x \ Kp \ x \ ET \ x \ ED \ x \ EF \ x \ CF}{BW \ x \ AT} \quad (2)$$

From equation 2: *ADDE* denotes average daily dermal exposure to heavy metals (mg/kg/day) in water; *SA* is the exposed area of skin (which equals to 18,000cm^2); *Kp* represents the dermal permeability coefficient (cm/h) of pollutants in water, of which Cr = 0.0002, Pb = 0.0001, Ni = 0.002 cm/h, while Cd, As, and Cu = 0.0006; *ET* indicates the exposure time in h/day (equivalent to 0.6 h/day); *CF* represents the conversion factor, which equals to 0.001 L/cm^3.

$$HQ = \frac{ADOE/ADDE}{RFD} \quad (3)$$

In equation 3, *RFD* stands for the oral/dermal reference dose (mg/L/day). *RFD* (oral/dermal) for Pb = 1.4/0.42; Ni = 20/5.40; Cd = 0.5/0.005; Cr = 3.0/0.015; and As = 0.3/0.8. A *HQ* greater than 1 indicates a non-carcinogenic health risk.

$$CR = ADOE/ADDE \ \ x \ CSF \quad (4)$$

From equation 4, *CR* stands for carcinogenic risk of oral or dermal exposure to heavy metals in water, and *CSF* means cancer slope factor (mg/kg/day). The *CSF* for Pb is 0.009, Cr is 0.50, Cd is 6.10, and Ni is 1.70. A *CR* value greater than 10^{-6} was considered potentially carcinogenic. The cancer risk values and their grades are presented in Table 1.

2.6 Health risk assessment of the fish samples

The cancerous and non-cancerous risks of daily ingestion of heavy metals in fish were calculated from equations 5-7 [19]:

$$EDI = \frac{C \ x \ IR}{ABW} \quad (5)$$

From equation 5, *EDI* stands for the estimated daily intake of heavy metals (mg/kg/day) from fish; *C* represents the concentration (mg/kg) of each heavy metal in fish; *IR* is the ingestion ratio, of which fish is 19.5 g/person/day; *ABW* is the average body weight (equivalent to the average body weight of resident Nigerians = 65kg):

$$THQ = \frac{C \ x \ IR \ x \ ED \ x \ EF}{ABW \ x \ AT \ x \ RFD} \ X \ 10^{-3} \quad (6)$$

Table 1: **Cancer risk values and grades [18]**

Risk grades	Range of risk value	Acceptability
Grade I (Very low risk)	$<10^{-6}$	Acceptable
Grade II (Low risk)	10^{-6}, 10^{5}	unconcerned about the risk
Grade III (Low medium risk)	10^{-5}, 5×10^{-5}	do no mind about the risk
Grade IV (Medium risk)	5×10^{-5}, 10^{-4}	care about the risk
Grade V (Medium high risk)	10^{-4}, 5×10^{-4}	concerned about the risk and ready to spend
Grade VI (High risk)	5×10^{-4}, 10^{-3}	take action on the risk
Grade VII (Very high risk)	$>10^{-3}$	resolve the risk at all costs

In equation 6, *THQ* stands for the target hazard quotient of heavy metals in the fish samples. The oral fish *RFD* (g^{-1} day^{-1}) of Ni = 0.05, Cd = 0.001, Pb = 0.004, Cr = 0.003. A *THQ* greater than 1 was considered potentially toxic.

$$CR = EDI \ x \ CSF \quad (7)$$

Note: All the variables in equation 7 have been explained in equation 4.

2.7 Data analysis

An Excel spreadsheet was used to present the values as mean ± standard deviation (SD). The software was also employed to work out various formulas used in the analyses.

3. Results and Discussion

3.1 Levels of heavy metals in the water and fish samples

The concentrations of Ni, As, Pb, Cr, and Cd in water samples obtained from Ogun River in Lagos are shown in Table 2. Except for As, the heavy metals were detected above the permissible limits. The levels of the heavy metals in the fish tissues also followed the same patterns as the water samples. These results show that the river is grossly polluted, and so consumption of the river water and fish may cause health hazards. Cd toxicity causes organ and tissue damage as well as immune dysfunction [20]. Long-term exposure to Ni can cause cardiovascular and renal disorders [21]. Chromium (VI) is a known carcinogenic compound and, recently, evidence suggests that chromium (III) can rupture the cell membrane and induce DNA damage [22,23]. Pb exposure has been linked to brain damage, cardiovascular disease, and urinary and respiratory issues [24]. The results of the current study are consistent with nearly all previous studies conducted on the river. Notably, the results are consistent with those of Nwude *et al*. [25], who detected non-tolerable levels of Pb and Cr in the Ogun State axis of the river. The results are also in line with those of Adeniyi *et al*. [26], who reported non-permissible levels of Pb, Cd, Mn, and Fe in water samples collected from the Ketu (Lagos State) axis of the river. Ayanda *et al*. [27] also detected unacceptable concentrations of Mn, Cd, Zn, and Ni in the tissues of fish collected from the Abeokuta axis of the river. However, the results contradict those of Adeosun *et al* [28], who found no abnormalities in the levels of heavy metals in water and fish obtained in Abeokuta, in the Ogun State axis of the river. It is noteworthy that the study with a dissenting result was conducted in Abeokuta North (the upper course of the river), which is comparably less industrialized and less used by humans. Overall, the levels of heavy metals in the fish tissues were greater than in the water, which suggests that the heavy metals bio-accumulate in the fish. According to Uysal [29] and Rajeshkumar and Li [30], fish can accumulate heavy metals in their bodies to levels greater than in their environment. In the current study, the intestines contained the highest concentration of heavy metals, followed by the gills, livers, and muscles. This is in line with the report of Akan *et al*. [31], who detected higher levels of certain heavy metals in the intestines of fish than in other parts. Rajeshkumar and Li [30] also detected higher levels of heavy metals in the gills of fish compared to other parts. Dural *et al*. [32] observed that the muscle of fish accumulates lower heavy metals than other parts such as the intestine, gills, liver, and skin. Fish's gills are a major entry point for water current and metal ions, which explains the high levels of heavy metals in the gills. Heavy metals are non-biodegradable and so can bio-accumulate over time in the internal organs of fish, such as the liver, kidney, and intestine. Hence the higher concentrations of heavy metals in internal organs than in the fish muscles and the environment (water). The liver engages in detoxification, which may be responsible for its lower concentrations of heavy metals than the intestines. Ni had the highest concentrations in both the water and fish samples, followed by Pb, Cd, and Cr. High Pb and Ni concentrations suggest industrial, mining, and artisanal discharges such as car acid batteries and metal scraps, among others [33]. The sources of Cd and Cr in a body of water are erosion discharges from their natural deposits as well as industrial discharges [34]. Generally, domestic waste is the main source of pollutants in the river. Settlers, who span the entire length of the Lagos axis of the river, dump sewage, excreta, urine, and refuse into the river. Other sources of pollutants in the river include municipal, industrial, agricultural, and artisanal wastes. The river's water is discolored and elicits offensive odors.

Table 2: Levels of heavy metals (mg/l) in water samples collected from Ogun River in Lagos

Heavy metal	Concentration (mg/l)	Limit [35]
Pb	1.582± 0.427	0.01
Ni	3.16±0.333	0.02
Cd	0.74±0.505	0.003
Cr	0.32±0.026	0.05
As	BDL	0.01

Values were expressed as Mean ± SD; BDL = below detectable levels

Table 3: Levels of heavy metals (mg/kg) in fish samples collected from Ogun River in Lagos

Organ	Pb	Ni	Cd	Cr	As
Gills	8.08± 0.076	14.63±0.353	4.19±0.333	1.18±0.035	BDL
Liver	7.03±0.031	12.11±0.099	6.05±0.036	1.17±0.298	BDL
Muscles	9.14±0.054	8.77±0.390	2.36±0.020	0.77±0.076	BDL
Intestine	11.82±1.684	22.46±1.675	7.54±0.505	5.75±0.869	BDL
Limit (WHO, 2006)	0.40	0.60	2.0	0.15	-

Values were expressed as Mean ± SD; BDL = below detectable levels

3.2 Health risk of the heavy metals in the water and fish samples

Table 4 reveals the *ADOE*, *ADDE*, and *HQ* of Ni, Cd, Pb, and Cr in the water samples. The *ADOE* and *ADDE* of the water samples were within the recommended daily intake (*RDI*), except for the *ADDE* of Ni and Cd. This suggests that the risk of daily dermal exposure to Ni and Cd in the water samples is significant enough to cause skin problems. Ni is one of the most common causes of allergic contact dermatitis [36]. Cd poisoning can cause skin problems and increase the severity of ulcers [37]. The *HQ* of *ADOE* and *ADDE* to the individual heavy metals was less than the threshold of 1. However, while the *THQ* of *ADOE* for all the heavy metals was within the threshold, the *THQ* of *ADDE* was above. This suggests that the additive combination of all the evaluated heavy metals can cause skin problems. Table 5 shows that all the assessed heavy metals can induce cancer risk via oral ingestion of the water samples. While Pb concentrations can induce cancer risk grade V (mild risk), Ni, Cd, and Cr can induce grade VII cancer risk (extremely high risk). These results are consistent with those of Ajagbe *et al.* [38], who reported cancer risk from certain environmental pollutants in the water and sediments obtained from the Mile 12 axis of the river. Awomeso *et al*. [39] also reported a health risk of heavy metals in water samples collected in the Ogun State axis of the river. Moreover, Olabode *et al*. [40] reported the health risk of heavy metals in groundwater in some communities along the Mile 12 axis of the river. However, Jubril and Okeyode [41] did not find any hazard or carcinogenic risk of radioactive elements in sediments obtained from the Mile 12 axis of the river.

The *EDI* of Pb, Ni, Cd, and Cr through the consumption of the fish samples is shown in Table 6. The *EDI* of the heavy metals was above the permissible limits in all the organs, which indicates that the consumption of the fish can cause health hazards associated with overexposure to various heavy metals mentioned earlier. However, the *HQ* of the individual heavy metals was less than 1, except for Pb and Cd (Table 7). This suggests that only the risks posed by Pb and Cd are significant.

Table 4: Average daily oral exposure (*ADOE*), average daily dermal exposure (*ADDE*), and hazard quotient (*HQ*) of heavy metals (mg/day) in water samples collected from Ogun River in Lagos

Heavy metal	*ADOE*	*ADDE*	*RDI*	*HQADOE*	*HQADDE*
Pb	0.045	0.024	0.21	0.032	0.057
Ni	0.090	0.975	0.500	0.005	0.181
Cd	0.021	0.068	0.06	0.042	0.136
Cr	0.009	0.010	0.20	0.003	0.653

RDI stands for recommended daily intake [15]

Table 5: Cancer risk of heavy metals in water samples collected from Ogun River in Lagos

Heavy metals	Cancer risk	Risk grades
Pb	2.8×10^{-4}	Grade-V
Ni	8.5×10^{-3}	Grade-VII
Cd	2.56×10^{-1}	Grade-VII
Cr	1.5×10^{-3}	Grade-VII

Table 6: Estimated daily intake (*EDI*) of heavy metals (mg/kg) in the fish samples harvested from Ogun River in Lagos

Organs	Pb	Ni	Cd	Cr
Gills	2.25	4.08	1.17	0.33
Liver	1.96	3.37	0.16	0.33
Muscles	2.55	2.44	0.66	0.21
Intestine	3.29	6.26	2.10	1.60
Limit [43]	0.24	0.50	0.06	0.05

Table 7: Target hazard quotient (*THQ*) of heavy metals in the fish samples harvested from Ogun River in Lagos

Organs	Pb	Ni	Cd	Cr
Gills	1.69	0.24	3.50	0.33
Liver	1.47	0.20	5.06	0.32
Muscles	1.91	0.15	1.97	0.21
Intestine	2.47	0.38	6.30	0.84

Table 8 shows the carcinogenic risks of the individual heavy metals in the various organs of the fish. The carcinogenic risk of all the heavy metals was above the threshold of 10^{-6} in the various organs of the fish samples. These results agree with Adegbola *et al*. [42], who reported a cancer risk of Cd and Ni in the fish obtained from the river's Abeokuta, Ogun State axis. Unfortunately, there was a dearth of documented relevant literature to further compare with the results of the current study.

Table 8: Cancer risks of heavy metals in the fish samples harvested from Ogun River in Lagos

Organ	Pb	Ni	Cd
Gills	2.00×10^{-5}	6.90×10^{-4}	6.09×10^{-4}
Liver	2.10×10^{-5}	5.70×10^{-4}	1.01×10^{-3}
Muscles	1.29×10^{-5}	4.15×10^{-4}	3.94×10^{-4}
Intestine	2.96×10^{-4}	2.06×10^{-2}	1.26×10^{-3}
Permissible limit	1×10^{-6}		

4. Conclusion

The findings of the study revealed that the water and fish samples from the Mile 12 axis of the Ogun River contained non-permissible levels of Pb, Cd, Cr, and Ni, but As was not detected. The *EDI* of the heavy metals, the *HQ* of Pb and Cd, and the *CR* of all the heavy metals in the fish samples were beyond the recommended limits. The *ADDE* to Ni and Cd, as well as *THQ* and *CR* of all the heavy metals in the water samples, were also above the permissible limits. This indicates that consumption of fish and water from the river can induce health risks.

5. Recommendation

Based on the findings of the study, the following are suggested:

- Dumping of wastes in or along the river should be discouraged.
- Residents should treat water from the river before using it or consuming it.
- Consumption of fish from the river should be discouraged until the river water is remediated and the fish are certified safe.
- There is a need for public awareness about the risk of drinking or using contaminated water.
- Agencies in charge of the river should ensure its safety.
- Similar studies like the current study are necessary.

Acknowledgement : Not applicable.

Disclosure statement

Conflict of Interest: The authors declare that there are no conflicts of interest.

Compliance with Ethical Standards: This article does not contain any studies involving human or

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