**Accumulation of Heavy Metal in Some Fish Species from Oron River Metropolis, Akwa Ibom State, Nigeria**

**ABSTRACT**

This study aimed to investigate the heavy metals in fish species in Oron metropolis, Akwa Ibom State, Nigeria. The pollution of the aquatic environment with heavy metals has become a worldwide problem and of scientific concern since heavy metals are not degradable and may pose toxic effects on organisms. This study was carried out in fish species (*Clarias gariepinus, Oreochromis niloticus, Sardina pilchardus* and *Scomber scombrus*) harvested from Oron river. Five samples per species were used following standard digestion procedures using an Atomic Absorption Spectrophotometer (AAS). Data collected were subjected to ANOVA, and student’s T-test were used for analysis. The results showed that lead (Pb) accumulated were slightly higher in the muscles than in the gills while Zinc accumulated more in the muscles than in the gills. Zn concentrations in the muscles of the fish species were significantly different from those in the gills. Zinc concentration in both gills and muscles is in the following order: *Clarias gariepinus* > *Oreochromis niloticus* > *Scomber scombrus >* *Sardina pilchardus.* Cadmium was higher in Scomber for both gills and muscles and in the order of Markerel > Catfish > Sardine and Tilapia respectively. Copper followed the order *Sardina pilchardus* > *Scomber scombrus* *> Clarias gariepinus* and *Oreochromis niloticus* for gills and *Scomber scombrus* *> Sardina pilchardus* > *Clarias gariepinus* and *Oreochromis niloticus* for muscles.

**Keywords: Heavy metal, concentration, Aquatic species, Oron River metropolis, Akwa Ibom State.**

**1.1. Introduction**

Fish (both fin and shell) is the main source of dietary protein in the coastal areas of Nigeria. Indeed, data from the Ministry of Agriculture indicate that over 64% of the rural communities dwelling in the coastal areas live solely on fish as their protein source (Ahmed *et al*., 2015). Over 80% of available food fish in this area comes from artisanal fishing from natural waters (Rahman and Singh, 2019). Pond fish culture has also gained a sizeable degree of prominence, especially as the natural stocks are being depleted steadily, owing to overfishing and severe anthropogenic perturbation of the environment. Indeed, the budding aquaculture industry in this area is evolving rapidly to cope with the shortfall in food fish production from the wild (Porcheron *et al.,* 2013). The productivity and survival of fish have been threatened by a series of factors which include the high cost of fish feed (Okon *et al.,* 2020), disease and infection (Silas *et al.,* 2024), unstable, uncontrolled and unmonitored water qualities (Essien *et al.,* 2024a), anthropogenic activities (Akpabio *et al.,* 2024) such as heavy metals and others.

The pollution of the aquatic environment with heavy metals has become a worldwide problem and of scientific concern since metals are not degradable and may pose toxic effects on organisms (Abiaobo *et al.,* 2017). Examples include Cadmium (Cd), Chromium (Cr), Lead (Pb) Manganese (Mn), Mercury (Hg), Nickel (Ni), Thallium (Ti) and Zinc (Zn), Cobalt (Co) etc., that have a particular significance in ecotoxicology, since they are highly persistent (Storelli *et al.,* 2011). Toxicity is realized when these heavy metal levels are higher than the recommended limits. Other sources of the metals include a variety of anthropogenic activities which are affected by seasons (Oguzie *et al.,* 2012).

Heavy metal (HM) pollution is of widespread concern for the ecological management of streams and rivers. Drainage water from both active and abandoned mines may be the major source of heavy metal contamination in mountain streams (Akpabio *et al.,* 2024). Environmental pollution has become an extensive and dangerous problem as a consequence of industrial and human activities (Nwadinigwe *et al.,* 2015). A very important fact about heavy metal poisoning is that they are not easily excreted out of the body, and its effect on the body is not immediate; therefore, individuals can accumulate the heavy metal over a long period without knowing, only to manifest much later in life (Oguzie and Izevbigie, 2012). One source of heavy metals in the aquatic ecosystems is effluents from mining operations. Other sources include different industrial effluents, domestic sewage, and agricultural runoff (Ustaoglu *et al.,* 2020). After release from both natural and anthropogenic sources, trace metals contaminate natural water bodies, sediments, and soils (Ahmed *et al.,* 2015). Since most of the inhabitants in rural communities do not have access to modern facilities, some communities that are located along streams and rivers discharge their waste directly into such water bodies (Okori and Ekanem, 2022). The contamination of aquatic systems by heavy metals, especially in sediments has become one of the most challenging pollution issues owing to its toxicity, abundance, persistence and subsequent bioaccumulation in benthic organisms (Fu *et al.,* 2013; Ubong *et al.* 2023). Serious checks on water sources must be made by ensuring appropriate treatment of the water and a total avoidance of indiscriminate dumping of garbage near these sources to ascertain their portability (Ubong *et al.* 2015).

Since heavy metals are non-biodegradable, once they enter into an environment, they will stay there for a long time (Rahman and Singh, 2019). They are metals with relatively high densities, atomic weights, or atomic numbers, high electrical conductivity, malleability, and luster, which voluntarily lose their electrons to form cations (Abiaobo *et al.,* 2017). They possess a specific density of more than 5g/cm3 and are an important group of chemical pollutants in food en route humans (WHO, 2017a). They are considered serious pollutants because of their toxicity, persistence and non-biodegradable conditions in the environment, thereby constituting a threat to human beings and other forms of biological life (Adeleken and Abegunde, 2011). The discharge of heavy metals into rivers or any other aquatic environment can change both aquatic species diversity and ecosystems due to their toxicity and accumulative behaviour (Muyssen *et al* 2012). Heavy metals dissolved in water also endanger the lives of the public who use it for drinking and irrigation. When used for irrigation heavy metals have the danger of being incorporated into the food chain and therefore ingested by the public (Wogu and Okaka, 2011). However, based on the importance and physiological roles played by heavy metals, they are classified into different groups. Iron (Fe), cobalt (Co), nickel (Ni) and zinc (Zn) are classified as essential HMs, whole cadmium (Cd), lead (Pb), and mercury (Hg) are classified as toxic by United States Environmental Protection Agency and World Health Organization (USEPA 2011; WHO, 2017b). The consumption of heavy metals could be highly hazardous depending on the consumed amount. However, bioaccumulation of low concentrations of toxic heavy metals (Cd, Pb, and Hg) over a long period can be very dangerous to life (Celik and Oehlenschlager, 2012). The toxicity of heavy metals is due to the effect of such metals on cellular membranes, vital organelles, and biochemical processes driving enzymes as well as their contribution to the development of reactive oxygen species (Mahurpawar, 2015). Therefore, consuming toxic heavy metals at doses greater than the recommended limits could affect the whole body’s function and lead to death (Zaynab *et al.,* 2022).

Zinc, copper, and iron play a significant part in biological systems and typical biological processes in living organisms (Saleh *et al.,* 2020). Metals and metalloids such as arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) derived from both natural and anthropogenic sources are considered toxic substances and their presence in excessive amounts can cause serious health issues (Porcheron *et al.,* 2013). They enter the aquatic environment and consequently the food chain by bio-amplification and bio-magnification to ultimately reach humans (Rahman and Singh, 2019).

Due to their toxicity and accumulation in biota determination, the level of heavy metals in commercial fish species has received considerable attention in different countries (Varol and Sünbül, 2020). There has been an increasing interest in the utilization of fish as bio-indicators of the integrity of aquatic environmental systems in recent years (Tas *et al.,* 2019). Fish lie at the top of the aquatic food chain and may concentrate large amounts of some metals from the water. Fish take heavy metals from the primary route for the uptake of water-borne pollutants and accumulate them in their tissues (Zaynab *et al.,* 2022) which are very detrimental to human health as it is one of the most common and appreciable protein sources in Oron, Akwa Ibom State, Nigeria.

This study is aimed to determine the current status of heavy metals in commonly edible consumed fish species about standard acceptable limits and its effects on human in Oron metropolis.

**2.0. MATERIAL AND METHODS**

**2.1. Study Area**

The study was carried out in major fish markets within Oron metropolis, Akwa Ibom State, Nigeria. The market women get their fish majorly from riversides in Akwa Ibom State.

Oron channel in Osung area of Oron city which is host to Nigerian maritime academy is located in Akwa-Ibom state which is in the south south of Nigeria with geographical co-ordinates of 4.833 latitude and 8.233 longitudes approximately. The inhabitants are mainly farmers and fishermen and women because of the fertile soil and Oron channel nearby respectively with geographical coordinates of lat. 4o48’0’’ and long. 8o6’60’’.

**2.2. Sample Collection and Preparation**

The fish samples (*Clarias gariepinus, Oreochromis niloticus, Sardina pilchardus* and *Scomber scombrus*) were procured from marketers after being purchased from fisher men. The samples (5 samples per specie was used) were taken to laboratory in a container with ice blocks to avoid deterioration. The fish were dissected and their parts (muscles and gills) were separated. According to APHA (2016) standard, the Atomic Absorption Spectrophotometer Machine was used to determine the level of heavy metals present in each of them.

**2.3.** **Digestion Procedure**

Dry tissue samples of fish samples weighing 0.5 g were digested with 0.5 ml of concentrated nitric acid (HNO3) the digestion was carried out in a fume cupboard and water bath were switched on to stabilise and attained 100°C using water bath digestion. The completely digested samples were filtered using what-man filter paper and diluted to 100 ml in a standard volumetric flask with distilled water. It was analyzed in Atomic Absorption Spectrophotometer (AAS) as described by (AOAC, 1990).

**2.4. Metal Determination and AAS Condition**

The metals were analyzed using an Atomic Absorption Spectrophotometer equipped with MS Window application software. The AAS determines the presence and concentration of metals such as in liquid sample. The AAS instrument looks for a particular metal by use of ultra-violet light (UV Light). When the sample of interest is aspirated into a flame, any metal present in the sample absorbs some of the light thus reducing its intensity. The instrument measures the change in intensity into an absorbance. As concentration goes up, absorbance goes up as well. AAS has high sensitivity which means that a solution with a concentration as low as part per million (PPM) range can be analyzed.

**2.5. Statistical Analysis**

Data collected were subjected to one-way analysis of variance (ANOVA), and student’s t-test were used to assess whether heavy metal concentrations varied significantly between fish species (AOAC, 1990).

**3.0 Result and Discussion**

**3.1. Results**

The heavy metal content in the gills and muscles of the commonly consumed fish; Catfish, Scomber, Sardine and Tilapia from markets in Oron metropolis in Akwa Ibom State were assayed and the heavy metal assayed for includes; Pb, Zn, Cd and Cu. Concentrations of Pb, Zn, Cd and Cu in the gills of the analyzed four fish species are presented in Table 1 as mean ± SD.

**3.1.1. The mean heavy metal levels in the fish gills**

There was no difference among the heavy metal concentrations in the gills of different fish species. In general, mean concentrations of Lead in the gills were not significantly different (*p*<0.05) in all species; which ranged between 0.01-0.03, whereas recorded results for Zinc were statistically significant with Sardine amongst others. Cadmium and copper also showed no significant difference across all species. Table 1 shows the significant differences (*p*<0.05) in the accumulation levels of metals in the gills of species.

**Table 1: The mean heavy metal levels (mg/kg) in fish gills**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Metals** | ***Clarias*** ***Gariepinus*** (M±SE) | ***Scomber scombrus*** (M±SE) | ***Sardina pilchardus*** (M±SE) | ***Oreochromis niloticus*** (M±SE) | **Overall mean** (M±SE) | **WHO (2015)** |
| **Pb** | 0.02±0.01a | 0.01±0.01a | 0.01±0.01a | 0.03±0.01a | 0.01±0.01 | 0.01 |
| **Zn** | 22.4±0.33b | 19.6±0.03b | 10.3±0.03a | 19.7±0.06b | 18.0±2.64b | 50.00 |
| **Cd** | 0.03±0.02a | 0.05±0.00a | 0.02±0.00a | 0.02±0.01a | 0.03±0.01a | 0.005 |
| **Cu** | 0.02±0.01a | 0.03±0.00a | 0.06±0.02a | 0.02±0.00a | 0.02±0.01a | 30 |

***a,b denote significantly different values in a row at p<0.05 level by one-way ANOVA and student’s t-test.***

**3.1.2. The mean heavy metal levels (mg/kg) in the fish muscles**

Only Zinc and copper also showed significant difference (*p*<0.05) amongst others, and *Clarias gariepinus* and *Oreochromis niloticus* against others respectively.

**Table 2: The mean heavy metal levels in fish muscles**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Metals** | ***Clarias*** ***gariepinus* M±SE** | ***Scomber scombrus* M±SE** | ***Sardina pilchardus* M±SE** | ***Oreochromis niloticus* M±SE** | **Overall mean** (M±SE) | **WHO (2015)** |
| **Pb** | 0.02±0.02a | 0.02±0.01a | 0.01±0.01a | 0.03±0.00a | 0.02±0.01a | 0.01 |
| **Zn** | 24.0±0.03b | 22.3±0.03b | 12.6±0.02a | 22.3±0.03**b** | 20.3±2.59b | 50.00 |
| **Cd** | 0.03±0.01a | 0.06±0.02a | 0.02±0.01a | 0.02±0.01a | 0.03±0.02a | 0.005 |
| **Cu** | 0.02±0.01a | 0.09±0.03b | 0.06±0.02b | 0.02±0.01a | 0.03±0.03a | 30 |

***a,b denote significantly different values in a row at p<0.05 level by one-way ANOVA and student’s t-test.***

3.2. **Discussion**

The result from the research on heavy metals in some fish species *Clarias gariepinus, Scomber scombrus*, *Sardina pilchardus* and *Oreochromis niloticus* sold in the market in Oron metropolis indicates that the river contains heavy metals which are harmful to the fish and also to some extent, human that consumes them if consumed in large quantity. The life span of the fishes, their yield, and their growth may also be affected by the presence of these metals in the water in which all their activities take place; however, it has not yet been known whether the fishes in the river have been severely affected by heavy metals based on the minute and insignificant results obtained from this study.

Generally, except Zinc, all metal sowed very low concentrations. This is in line with Siong *et al*., (2016) that the mobility and availability of heavy metals in aquatic environments are primarily controlled by water quality parameters including pH, dissolved oxygen and organic matter content. The physiochemical parameters of the study area in this research were not considered, however, Nwamba *et al*., (2017) and Akpabio *et al.,* (2024) opined that, environmental factors such as pH, turbidity, dissolved oxygen, temperature and conductivity influence the rate of reaction of the pollutants entering the water or the lethal effects on the aquatic organisms.

Pb is not essential for fish, and excessive amounts can cause deficits or decreases in the survival, and growth rates, as well as increased mucus formation. The levels of Pb found in the muscles and gills of the different fish species considered in this study were below the detection limits (0.05 kg-1). This indicates that all the fish species in this study are considered safe for human consumption since do not contain a very insignificant level of lead which is very dangerous to human health.

The levels of Lead in the fish species organs considered in this study agree with Ubong *et al.,* (2023) and Olatunji *et al.,* (2021) that reported low levels of lead in fish samples in Idu Uruan River and Oron River respectively, all in Akwa Ibom State. The Pb levels of fish gills and muscles in this present study were found to be lower than the studies performed by Copat *et al.,* (2013); Martínez-G´omez et al., (2012); Medeiros *et al.,* (2014) and Varol and Sünbül (2018). But agrees with Akpanyung *et al.,* (2014) and Nwamba *et al.,* (2021) that reported low levels (0.01-0.02) of Lead in the gills of fish from Ibaka River, Akwa Ibom State and Enugu State.

Consumption of high concentrations of Lead (Pb) in the fish tissue may show cognitive development, impair intellectual performance in children and is implicated in causing an increase in blood pressure and cardiovascular diseases (Siong *et al*., 2016). It is known as one of the most hazardous heavy metals. It causes an elevation in hypertension and the promotion of cardiovascular disease in adults and reduces intellectual activities in children (Commission of the European Communities, 2006).

Zinc concentrations in fish gills and muscles have been recognized as the most accumulated metals in fish species after iron (Türkmen *et al.,* 2008). Zn concentrations in muscles were observed at a high level of 22.4 mg/kg in *C. gariepinus* and the lowest concentration of 10.3 mg/kg in *S. pilchardus* for gills and 24.0 and 12.6 in muscles respectively. Zinc can be safe under the limit of 50 mg/kg wet weight in the muscle of fish (Mahboob *et al.,* 2014). It was also observed that there was a significant difference in Zn level of the four species when the Zn levels were examined at (P < 0.05). Eneji *et al.,* (2011) reported average Zn concentrations of 7.15 mg/kg in the fish gills and 5.66 mg/kg in the fish muscles from River Benue. **Lower mean concentration levels of** Zn (3.85 mg/kg) were measured in the muscles of *Mugil species* from Lake Qarun, Egypt and lower average Zn concentrations in *M. cephalus* muscle (5.82 mg/kg) have been reported from India (Authman *et al.,* 2007). In general, the average Zn concentrations in the three fish species were found below the permissible range of 30 mg/kg for consumable fish. Unlike this present result, Olatunji *et al.,* (2021), Nwambe *et al.,* (2021) and Wogu and Okaka (2011) reported extremely low levels of Zinc concentration in fish species from Cross River State and Enugu State respectively. Ayotunde *et al.,* (2012) also found a low accumulation of zinc in the gills of the *Chrysichthys nigrodigitatus* in Cross River. These low levels of Zinc in fish muscles appear to be due to low levels of binding proteins in the muscles.

Although zinc is an essential element, at high concentrations, it can be toxic to fish, cause mortality, growth retardation, and reproductive impairment (Sorenson 1991). Zinc is capable of interacting with other elements and producing antagonistic, additive, or synergistic effects (Eisher 1993). Sequel to bioaccumulation, Zinc is likely to present a contaminant hazard to fish in Oron metropolis.

In this study, Gills recorded higher concentrations of Zinc than in muscles. Fish need more Zinc in the muscles than in the gills because it is essential for muscle contraction, growth, protein synthesis and enzymatic functions. However in this study, the reverse was the case. This can be attributed to a zinc-deficient diet, stress and certain environmental conditions.

The higher concentration of cadmium in fish than periwinkle from Uta-ewa Creek may be attributed to the higher trophic level of fish ingesting many food resources hence bioaccumulation of more heavy metals from effluents from Aluminum Smelter Company discharged into the creek (Ekpo and Ukpong, 2014). From this study, the mean value of Cd concentration recorded in all fish species was lower when compared to WHO recommended limit of 0.5mg/kg for fish food (FEPA, 2010). Cadmium is a by-product of lead and zinc and is used in nickel-cadmium batteries, thus ingestion of cadmium can cause vomiting, abdominal cramps and headache. Consumption of aquatic resources which is concentrated with cadmium from Oron metropolis can barely cause serious hazards except at a long bioaccumulation.

These results contradict Kasmi *et al.,* (2013), Chahid *et al.,* (2014) and Traina *et al.,* (2019) that reported a higher level of Cadmium in fish gills and muscles. Mean Cd concentrations in the muscle tissue of all fishes in the present study were similar to Nwamba *et al.,* (2021)’s report. The mean concentrations of Cd in the fish from the three water sources were quite low but slightly above the maximum allowed WHO limit (0.003mg/kg). Low level of Cd (0.0072 mg/kg) was also reported in the water from Niger Delta region of Nigeria by Wogu and Okaka (2011). It was also similar to Olatunji *et al.,* (2021) result in fish from Oron River, Akwa Ibom State.

Cadmium can be accumulated with metallothioneins and uptake of 3–330mg/day is toxic and 1.5–9 mg/day is lethal to humans (Ekeanyanwu *et al.,* 2011). Cadmium injures kidneys and causes symptoms of chronic toxicity, including impairment of kidney function, poor reproductive capacity, hypertension, tumours and hepatic dysfunction (Chahid *et al.,* 2014).

Gills are also reported to act as a storehouse of cadmium in experimental studies (Fafioye *et al.,* 2004; Ramesh and Nagaranjan, 2007). Wong and Wong (2000) studied morphological and biochemical changes in the gills of Tilapia (*Oreochromis mossambicus*) after experimental cadmium exposure. In scanning electron microscopic studies, they found an augmentation of microbridges in pavement cells and an increase in the apical membrane of chloride cells. They further reported chloride cells as a prime target of cadmium toxicity, resulting in fish hypocalcemia. Other organs like the intestine and gonads of fishes also appear susceptible for ill effects of cadmium toxicity (Singh *et al.,* 2007). Exposure of Cd and especially chronic exposure can cause renal dysfunction, calcium metabolism disorders and also increased incidence of some forms of cancer (Rashmi and Pratima, 2013).

The concentrations of Copper in all four species were below WHO maximum allowable limit. The levels of Zn observed in the tissues of all the samples were within the range of WHO maximum allowable limit (3-5.00mg/kg). The concentrations of heavy metals in fish have been reported to depend upon the rate of uptake through the gut from food and the rate of excretion (Bull *et al*. 1981). The accumulation of copper in the gills may be due to adsorption to the gill surfaces and dependent on the availability of proteins to which the copper may bind. The low accumulation in this result may be due to the development of some defensive mechanism such as excessive mucous secretion and clogging of gills. The slow penetration of copper across the gills may be the reason for the low toxicity of this metal to *these* fish species. The highest concentration of copper (0.03±0.01 mg/kg) was detected in the gills of *O. niloticus*, while the lowest detected limit (0.01±0.01 mg/kg) were found in the gills of *Scomber scombrus* and *Sardina pilchardus*.

Unlike our results, Ayotunde *et al*. (2012) recorded high level of copper in all the fish samples from fresh water in Cross River. This may be because, the liver is a primary targeted organ for the accumulation of this element. For the gills sample, it may be due to the fact that freshwater fish’s gills might be expected to be the primary route for the uptake of water-borne pollutants (Allen and Wilson, 1991). Jafiya *et al.,* (2022) also reported higher concentration of Cd (2.52mg/kg) in Catfish species from Komadugu-Yobe River, Gashua, Yobe State, North-East Nigeria. Eneji *et al.,* (2011) also reported high levels of Cu in Catfish from River Benue.

WHO (2015) reported that copper toxicity in fish is taken up directly from the water via gills and stored in the liver, the present study showed a similar accumulation of copper in the gills and liver. Copper can combine with other contaminants such as ammonia, mercury, and zinc to produce an additive toxic effect on fish (Singh *et al.,* 2007). Scomber fish recorded higher (0.09) concentration level of Copper in the muscles than Catfish and Tilapia (0.02). This is justifiable because of their different environment as Markeral are saltwater species unlike Catfish. Copper is found higher in salt water than in freshwater, as a result of Markeral has a greater opportunity to absorb Copper from the environment during feeding, respiration and other biological activities than Catfish. As for Tilapia, their diet contains less Copper and it has the ability to regulate the amount of Copper in the body.

All these heavy metals observed showed higher concentrations in the gills of the fish samples than the muscles. This may be because the gills of fishes are directly in contact with the contaminated medium (these metals are first absorbed through the gills) and also have the thinnest epithelium when compared to other organs (Akpanyung *et al.,* 2014).

**Conclusion**

The rising level of anthropogenic perturbations of the aquatic ecosystems has remained a major source of keen concern. The input of heavy metals in such systems has significantly increased due to unregulated activities, majorly from the oil and gas sector and other related activities in the use of the aquatic systems for transport activities etc and these have placed a lot of fish and shellfish and consequently inhabitants of the region at high risk. The result showed that the fish species sold in markets in Oron metropolis, Akwa Ibom State, Nigeria is not significantly polluted by heavy metals. Though they are present in minute quantities but are bioaccumulated Although, according to standard limit the heavy metals pose no threats to consumers, the possibility of deleterious effects after long period cannot be ruled out.

**Recommendation**

Therefore, the a need for continual assessment of the level of pollution of this stream with metals from their sources to reduce the level of pollution by education and public enlightenment.

Regular biomonitoring and sustainable management of the fish sources are encouraged to reduce the amount of contaminant entering the water which may pose health risks to fish and consumers within and without Oron metropolis.

Further studies should be done to include more heavy metals to determine their contamination in other common consumable species and also extension to prey of these species; with consideration to food chain and feed web.

Also, researches need to be carried out to ascertain the blood level concentration of these heavy metals among consumers; likely the residents of the communities close to these rivers.

**Compliance with Ethical Standards**

**Ethical Approval**

The authors declare that the study was conducted in accordance with all applicable international, national, and/or institutional guidelines for the care and use of animals. The research did not involve blood extraction or sacrifice of fish samples. Additionally, the number of fish used (20 samples) did not exceed the threshold requiring ethical approval (200 samples and above) as per the local regulations. The study was performed on a private fish farm licensed by the State Government, which lies outside the jurisdiction of the Ethical Approval Research Committee in Nigeria. For these reasons, no formal ethical approval number was issued for this study.

**Data Availability**

The data that support the findings of this study are available from the corresponding author on request.

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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