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Water Characteristics Assessment, Bioaccumulation and Health Risk Evaluation of Possible Ingestion of Toxic and Essential Metals in *Chromidotilapia guntheri* Sourced from Ada River, West Africa

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Abstract: The water ecosystem has been acclaimed to be polluted with various chemicals that may pose possible risks to the biota therein and affect the end consumers who ingest them via the food chain system. This study evaluates the water characteristics, bioaccumulation and non-carcinogenic risk potentials in the ingestion of toxic metals like (Cu, Fe, Zn, Mn and Pb) in *Chromidotilapia guntheri* from Ada River. Samples were collected for six months (3 months dry and wet correspondingly) to cover the hydrological season. *Chromidotilapia guntheri* was collected by local fishermen with a local trap. No ethical considerations were needed for this study. Standard methods were used in the determination of the water characteristics. The findings from the study showed that all the parameters were significant ($p>0.05$) across all the stations studied. The seasonal assessment of the water parameters was highly significant ($p<0.001$) for DO, BOD_5, Ca, Mg, NO_3, PO_4, Cl, Cu, Pb and Mn. For water temperature, air temperature, pH, EC, TDS, Alkalinity, SO_4, hardness, Fe and Zn correspondingly, they were significant ($p<0.05$) across all the stations studied. Similarly, the seasonal variations of the heavy metals in the fish tissues showed that there was a significant difference ($p<0.05$) in Cu for both the wet and dry periods. However, Pb, Fe, Mn and Zn showed no significant difference ($p>0.05$) for both seasons. The average concentrations of Zn, Mn, Fe, Pb and Cu in the muscles of *Chromidotilapia guntheri* were 0.355±0.062, 0.824±0.803, 6.825±3.730, 0.163±0.053 and 0.779±0.522 mg/kg individually. The results obtained from this study show that the analyzed metals have Bioaccumulation Factors (BAFs) >1 which was also greater than the concentrations in water. This shows that the organism accumulated more metals in its muscles than what is found in its water environment. This may cause non-carcinogenic health issues like foodborne sickness, diarrhea and food intoxication. The results of the Hazard Index (HI) 0.127 of *Chromidotilapia guntheri* show that all the metals were less than the threshold value of 1. The results of the THQ (Target Hazard Quotient) showed the variations of the metals as Cu (0.040)> Mn (0.014)> Pb (0.002)> Fe (0.000)> Zn (0.000) correspondingly. More so, the results of the EDI (Estimated Daily Intake) showed the following rank pattern Fe>Mn> Cu> Zn > Pb. The low values (<1) observed for the HI, THQ and EDI, indicate that the species of fish is good for human ingestion at this period of study without any non-carcinogenic health risks. We recommend continuous monitoring of the Ada River to ascertain the trend of water characteristics and bioaccumulation of heavy metals in the water to regulate the possible activities causing this effect. There has not been any study on the bioaccumulation and health risks of this species. So, this stands as the research gap of this study.

Keywords: Reference Dosage, Carcinogenicity, Toxicity, Aquatic Biota, Metal Contents, Health Risks

Introduction

In the food chain structure, fishes inhabit the highest part of an aquatic system and they serve as food to humans in the form of proteins (Olajire *et al.* 2003; Anani and Olomukoro, 2018a). However, they are very susceptible to surface water toxicants like heavy metals which tend to bioaccumulate at a level beyond set thresholds and pose a probable health risk to humans or higher animals who ingest them (Olajire *et al*., 2003; Anani and Olomukoro, 2018b; Enuneku *et al*., 2018a).

In recent years, the health and ecological concerns linked to the pollution of the ecosystem with toxic metals have been on the rise globally (Bradl, 2005; Anani and Olomukoro, 2018b; 2021; Enuneku *et al*., 2018b; 2019; Anani and Olomukoro, 2020; Olatunji and Anani 2020). One of the ways toxic metals get through the food chain to humans is through the consumption of animals exposed to toxins via bioaccumulation. Aquatic animals like the fishes sourced from water bodies that have been acclaimed to be polluted pose possible risks to consumers who ingest them (Anani and Olomukoro, 2018a; Enuneku *et al*., 2018b).

Human exposure to toxic metals has risen significantly due to a sharp rise in their uses in the technological, domestic, agricultural and industrial sectors (Bradl, 2005). Therefore, concern for the valuation of toxic metals in the muscles of fish has become a topical issue of current research around the world (Enuneku *et al*., 2018a). Fishes are one of the suitable aquatic faunas used in the monitoring of pollutants (Van Ael *et al*., 2014; Cui *et al*., 2015). They usually bioaccumulate toxicants in their skin, gills and muscles indirectly or directly from their diets and the environment in which they live (Cui *et al*., 2015; Enuneku *et al*., 2018b).

Recent reports by Oguguah *et al*. (2017); Ekere *et al*. (2018); Authman *et al*. (2015); Jezierska and Witeska (2006) revealed information on the bioaccumulation and health risks from heavy metals on different species of fish. Toxic metal noxiousness, however, in aquatic resources differs amongst fish species owing to their structural interruption arising from their capability to intercept some physiological processes like cell-enzyme mediation (Abalaka *et al*., 2020). Thus, the assessment of the level of bioaccumulation in fish is very important because it serves as a potential pointer in the valuation of probable effects on the higher consumers (humans) along the food chain structure (Abalaka *et al*., 2020).

It has also been documented that essential metals like Zn, Fe and Cu play a vital role in the maintenance and regulation of the health of humans (Fu *et al*., 2019). However, toxic metals like Mn and Pb could elicit genetic disorders, neurotoxicity, embryotoxicity and cancers in humans even at a very low concentration (Fu *et al*., 2019).

So, this study evaluated the bioaccumulation factor of toxic and essential metals (Zn, Mn, Fe, Pb and Cu) in *Chromidotilapia guntheri* and possible human health risks via the ingestion of the fish species from Ada River. Several studies done on this river have not evaluated the bioaccumulation factor and human health risks apart from the water characterization. However, this stands as a research gap to other studies.

Materials and Methods

The Area of Study

The area of study is the Ada River situated in the North East of Edo State (Usen) in Ovia local government. The river is oligotrophic in nature. Around the stretch of the river are canopies of thick vegetation. The river lies between 005° 18' and 005° 26'E longitudes and 06° 38' and 06° 48' N latitudes Fig. 1.

The activities of humans that are common in this area of study are lumbering, block factories, grazing of cattle, farming, plantation of cocoa and fishing. The inhabitants of this community rely on the water for swimming, washing, drinking and other domestic use. The seasonal variations are wet and dry seasons (April to October and November to March) respectively. The rationale of this study is geared towards the human activities along the stretch of the river which may have potential effects on the surface water and its resources.

Sampling Stations

Three (3) stations were selected along the stretch of the river for the abstract of surface water samples. They were selected because of the human activities (farming, fishing and cattle grazing) there which may have significant impacts on the quality of the water and its resources.

Sampling Periodicity and Collection of Water Samples

Samples were collected between 08.00 and 10.00 h for six months (3 months dry and 3 months wet) correspondingly from November 2017-January 2018, to cover the dry season period and April-June 2018 for the wet season period. This was done to ensure the hydrological season was covered properly. The sampling regime was once a month. During this period, several

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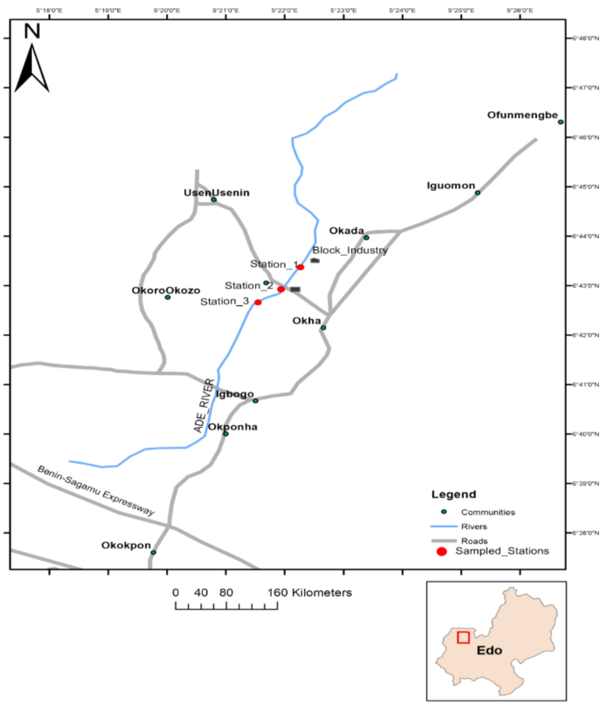

Fig. 1: Map of Ada River displaying the sampling stations

Fish Collections

The fish species *Chromidotilapia guntheri* were caught along the water course using the method of (Nwani *et al*., 2010). The taxonomic keys by Idodo-Umeh (2003) were used to identify the specific type.

(QA and QC) Quality Assurance and Quality Control

The QA and QC diagnostic procedures of (Hashmi *et al*., 2013; Anani and Olomukoro, 2021) were used to quantify the water quality data sourced from the river in the laboratory. The water samples were analyzed in 3 (three) portions for every 2 standard blank and 2.5 mg/L samples using a SOLAAR 969AA Unicam series atomic absorption spectrophotometer. This was followed by a recovery method for every water parameter at 90.5±0.80-96.9±0.35% established by the various curves of calibrations which determined the quality control standards. The chemicals utilized for the QA and QC diagnostic procedures were certified by a German and UK company which had about a 99.99% purity rate. Pyrex, the glassware utilized for this laboratory assessment was washed and rinsed with deionized ultra-fine water and later sodden in 10% HNO_3 for 1 day and later bathed with deionized ultra-fine water. Finally, the glassware was later placed in an oven at a temperature range between 59.90-60.5°C. The bottles used for this assessment were covered tightly before the final water analysis. The Limit of Detection (LOD) was detected using the below equations.

physical and chemical parameters were measured in situ like water, temperature, air temperature, EC and pH to ensure a full understanding of the environmental conditions that affect the water body.

LoD = LoB +1.655 (SD low concentration sample). Where Limit of Blank (LOB) was = mean blank +1.665 (SD blank) of the analytes. The Limits of Quantification (LoQ) were estimated from the lowest concentrations of the analytes which also depicts the imprecision and bias of the predefined objectives of the QA and QC.

Water Samples Analysis

Copen-Hagen CDM83 and GMBH D4040NEUSSI model meters made in China were used to instantly determine the Electrical Conductivity (EC) and hydrogen-ion concentration (pH) in surface water at the sampling locations. The probe was inserted into a glass beaker containing the water sample. The numbers were recorded after approximately 5 min. A liquid-in-glass thermometer was used to determine the water and air temperature respectively by adhering to the ASTM E337-15 standard. For the water temperature, the probe was dipped in the water. After about 5 min, it was taken out from the water and the readings were taken from each station sampled. As for the air temperature, the thermometer was held up for about 5 min. Then, the readings were taken and documented.

The ex-situ determination involved the analysis of heavy metals. A water sample was gathered in a spotless, transparent container. The metal contents were fixed by adding about 1 mL of HNO_3. A water sample was also taken and placed in a spotless, transparent container to determine the total hydrocarbon content.

All samples were carried to the lab for additional analysis and transported there in an ice chess thermo-cooler. Suspended Solids (SS) and Total Dissolved Substances (TDS) were measured in the lab using a HACH UV/VIS Spectrophotometer (model DR/2000) by using the photometric method (APHA, 2005; Anani *et al*., 2020). Based on the modified method of (APHA, 2005) by Anani *et al*., (2020), the Chemical Oxygen Demand (COD), DO and Biochemical Oxygen Demand (BOD_5) (Anani *et al*., 2020). The Atomic Absorption Spectrophotometer (AAS) Solaar 969 Unicam Series model was used to measure the heavy and trace metal contents according to the procedures described in Anani *et al*. (2020). The method (Ademoroti, 1996) was used to determine the total dissolved solids and sulfate. APHA (1998) colorimetric method was used to determine chlorine, nitrate and all other parameters of the surface water. ASTM (2019) technique was utilized to determine the phosphate content in the surface water.

Digestion and Preparation of Samples of Fish

APHA (1998) method for the evaluation of wastewater and water was used in the digestion and preparation of the fish samples. The Standard and Total Lengths (SL and TL) in centimeters (cm) of the fish sample were measured with the aid of a calibrated measuring board at the closest 0.1 cm. This is to ensure that the fish species condition factor and wellness are ascertained first to know if they can be used for the bioaccumulation assessment. Fish species without good condition factors and wellness cannot be used because they have already shown negative signs which will negate the importance of studying the trend of metal accumulation in their tissues. Positive signs of the fish growth and robustness an indications of good health which also show no bias in the selection for bioaccumulation study.

The samples of fish were later weighed on a Mettler P.E. 360 weight balance to the closest 0.1 g. The values obtained were recorded. After, about 1.0 g of the muscles of the fish species were harvested fresh and processed for digestion.

Four (4) standard procedures were used to determine the heavy metals, via a SOLAAR 969AA Unicam Series Atomic Absorption Spectrophotometer, from the fish muscle. A mixture of H_2SO_4, $HClO_4$, HNO_3 and H_2O in a ratio of 30: 30: 30:10, was used for the digestion procedure in 2 different vessels; a 50 mL 26×200 mm test tube (pyrex) and a thick-walled extended neck 50 mL volumetric bottle which was subjected to optimum temperature of 230°C at 40 min. The Detection Limit (DL) was set at 0.54 ngg^{-1}.

Ethical Consideration

Ada River was not placed under any harvesting prohibition at the time of this study. The *Chromidotilapia guntheri* were neither placed on the endangered nor the threatened lists, so the species collected do not need permission before collection.

Bioaccumulation Factor (BAF)

The modified BAF method by Anani and Olomukoro (2018a) was employed in this study. Anani and Olomukoro (2018b) stated that BAF >1 shows great potential for health risks:

$$BAF = \frac{Concentration\,of\ HM\,(heavymetal)\,in\,the\,sample\,of\ fish\,(mg/kg)}{HM\ in\,water\,(mg/kg)}$$

While *BAF* means bioaccumulation factors and HM means heavy metal.

Non-Carcinogenic Risk Evaluation

The non-carcinogenic risk evaluation is a health metric tool used in the quantification of the probable health risk of heavy metals found in the tissue or muscles of an organism, water and related food materials that can be ingested by humans. USEPA (2012) health risk indices like the Hazard Index, Target Hazard Quotient and Estimated Daily Intake (HI, THQ and the EDI) were used to quantify the possible non-carcinogenic risk of Zn, Mn, Fe, Pb and Cu in this study:

$$EDI = \frac{MI_f \times CM_f}{BW}$$

where, the mass of the ingested sample of fish per day is MI_f, the metal concentration in the sample of fish is CM_f and the Body Weight of an adult (BW) is = 60 kg. The method of Enuneku *et al*. (2018b) was used for the assumption of human food ingestion in Nigeria (9.0 kg) which is equal to the 24.70 g per day established by the (USEPA, 2012) for adult above 60 kg:

$$THQ = \frac{EF \times ED \times MI \times CM}{ORD \times BW \times AT} \times 10^{-3}$$

ED and *EF* = Exposure Duration and Exposure Frequency at 52.62 years and 365 days/year respectively. The Average non-carcinogenic Time (AT) is rated for 365 days/year multiplied by the ED. The reference dosage for the ingestion pathway is estimated for the following heavy metals as follows: Zn (3.0×10^{-1}), Mn (1.0×10^{-3}), Fe (Fe-7.0×10^{-1}), Pb (3.5×10^{-3}) and Cu (1.9×10^{-3}) (USEPA, 2012; Anani and Olomukoro, 2021).

Meanwhile, the HI of the heavy metals in the fish species was estimated using the method of Enuneku *et al*. (2018b):

$$HI = THQ1 + THQ2 + THQ3 + \cdots$$

where, *THQ1*, *THQ2*, etc., means target hazard quotient for heavy metal 1 (one), two (2) and so on. While (HI) means Hazard Index.

Analysis of Data

Analysis of Variance (ANOVA) in addition to the computation of mean and Standard Deviation (SD), minimum and maximum values, was used to test the significant difference in the physical and chemical conditions across the three stations set at a 0.05 confidence level using version 22 of the software statistical package (SPSS). Paired and sample t-tests were utilized to compare the bioaccumulation of heavy metals in the species of fish (*Chromidotilapia guntheri*). Excel version 2013 was used to calculate the bioaccumulation factors and non-carcinogenic pathways in humans.

Results

Physical and Chemical Properties of Water Samples

Table 1a shows the results of the physicochemical properties of water samples determined from the river. The maximum, minimum and mean values of all the parameters were recorded and they were compared with the National Standard for Drinking Water Quality (NSDWQ, 2007); (WHO, 2011b) World Health Organization acceptable limit for drinking water. Table 1b shows the seasonal dissimilarities of the physicochemical characteristics of water samples determined from the river.

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Table 1a: Spatial variation of physical and chemical parameters from Ada River, Usen

	Station 1			Station 2			Station 3				Limits	
Parameter/units	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	p-value	NSD WQ (2007)	WHO (2011)
Water Temp. (°C)	26.33±01.21	25.00	28.00	25.83±1.47	25.00	28.00	26.33±01.03	25.00	28.000	p>0.05		
Air Temp.(°C)	30.50±01.87	28.00	33.00	30.17±02.71	27.00	33.00	30.00±01.90	28.00	32.000	p>0.05		
pH	6.48±00.47	6.00	6.90	6.43±00.56	5.80	7.00	6.35±00.41	5.90	6.900	p>0.05	6.5-8.5	6.5-8.5
EC (µS/cm)	46.67±19.66	20.00	70.00	50.00±21.91	30.00	70.00	50.00±23.66	20.00	80.000	p>0.05	1000	1000
Turbidity (NTU)	10.33±03.88	5.00	15.00	12.33±03.78	9.00	19.00	12.17±04.62	7.00	20.000	p>0.05	500	3.00
SS (mg/L)	6.00±03.03	4.00	11.00	08.17±02.14	6.00	11.00	10.00±04.43	5.00	18.000	p>0.05	000	N/A
TDS (mg/L)	24.73±10.42	10.60	37.10	25.62±12.73	10.60	37.01	26.50±12.54	10.60	42.040	p>0.05	500	500
DO (mg/L)	6.45±00.93	5.20	8.00	6.28±01.30	4.90	8.60	6.02±01.04	4.80	7.800	p>0.05	7.50	5.00
BOD_5(mg/L)	3.15±01.10	2.00	4.50	2.73±01.55	0.80	5.00	2.30±01.21	0.60	4.300	p>0.05	5.00	5.00
Alkalinity (mg/L)	24.67±06.41	18.00	36.00	24.00±05.22	18.00	32.00	23.67±08.52	12.00	32.000	p>0.05	NA	
Ca (Calcium) (mg/L)	10.69±06.70	4.01	22.45	8.82±06.45	4.01	20.04	10.82±06.83	3.21	20.084	p>0.05	NA	
Mg (Magnesium) (mg/L)	2.19±01.26	0.97	3.89	3.41±01.95	1.46	3.89	2.92±01.38	0.97	4.380	p>0.05	0.30	
SO_4 (Sulphate) (mg/L)	8.83±07.60	2.00	14.00	8.67±07.37	2.00	17.00	10.67±06.98	4.00	18.000	p>0.05	100	100
Nitrate (mg/L)	2.00±01.04	0.55	2.98	1.66±00.83	0.70	2.12	2.18±00.89	0.98	2.900	p>0.05	500	50
Phosphate (mg/L)	0.24±00.04	0.21	0.31	0.24±00.03	0.21	0.30	0.28±00.04	0.23	0.330	p>0.05	500	10
Chloride (mg/L)	16.47±05.75	14.12	28.12	17.65±03.87	14.12	21.20	15.30±02.89	14.12	21.020	p>0.05	250	250
Hardness (mg/L)	35.33±17.28	18.00	62.00	36.00±19.06	16.00	60.00	38.67±16.28	18.00	54.000	p>0.05	300	300
Copper (mg/L)	0.25±00.07	0.15	0.34	0.26±00.09	0.14	0.35	0.32±00.12	0.18	0.490	p>0.05	1.00	2.00
Lead (mg/L)	0.03±00.02	0.02	0.06	0.03±00.02	0.02	0.06	0.03±00.01	0.02	0.050	p>0.05	0.01	0.01
Iron (mg/L)	1.11±01.10	0.07	2.36	1.61±01.66	0.17	4.40	1.50±01.64	0.06	4.130	p>0.05	0.30	0.01
Manganese(mg/L)	0.13±00.09	0.05	0.28	0.11±00.06	0.03	0.17	0.14±00.06	0.06	0.230	p>0.05	0.40	NA
Zinc (mg/L)	0.36±00.19	0.19	0.54	0.31±00.11	0.14	0.43	0.31±00.15	0.15	0.500	p>0.05	3.00	1.05

NB: NA means not applicable, p<0.05 specifies significant difference; p<0.001 specifies highly significant difference; p>0.05 specifies no significant difference

Table 1b: Seasonal variation in physical and chemical parameters from Ada River

	Dry period			Wet period			
Parameter	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Sig
Water temp. (°C)	27.11±0.78	26.00	28.00	25.22±0.67	24.00	26.00	p<0.001
Air temp. (°C)	32.00±0.87	31.00	33.00	28.44±1.13	27.00	30.00	p<0.001
pH	6.00±0.12	5.80	6.20	6.88±0.10	6.70	7.00	p<0.001
EC (µsc/m)	30.00±7.07	20.00	40.00	67.78±6.67	60.00	80.00	p<0.001
Turbidity (NTU)	8.67±1.94	5.00	11.00	14.56±3.21	10.00	20.00	p<0.050
SS (mg/L)	5.78±2.11	3.00	10.00	10.33±3.28	8.00	11.00	p<0.050
TDS (mg/L)	15.31±4.14	10.60	21.20	35.92±3.53	31.80	42.40	p<0.001
DO (mg/L)	5.60±0.67	4.80	6.80	6.90±0.97	5.90	8.60	p<0.050
BOD_5 (mg/L)	2.01±1.14	0.60	4.50	3.44±1.00	2.00	4.30	p<0.050
Alkalinity ($CaCo_3$)	26.44±8.41	12.00	36.00	21.78±2.33	18.00	24.00	p>0.050
Calcium (mg/L)	5.43±2.03	3.21	8.82	14.79±5.64	6.41	22.45	p<0.001
Magnesium (mg/L)	2.32±1.19	0.97	3.89	3.35±1.76	0.97	6.81	p>0.050
Sulphate (mg/L)	15.89±2.42	12.00	20.00	2.89±1.17	2.00	5.00	p<0.001
Nitrate (mg/L)	1.31±0.85	0.55	2.88	2.57±0.31	2.12	2.98	p<0.050
Phosphate (mg/L)	0.25±0.04	0.22	0.33	0.25±0.04	0.21	0.31	p>0.050
Chloride (mg/L)	15.69±3.11	14.12	21.18	17.26±5.12	14.12	28.20	p>0.050
Hardness ($CaCo_3$)	22.89±6.49	16.00	34.00	50.44±10.71	32.00	62.00	p<0.001
Copper (mg/L)	0.46±0.08	0.33	0.54	0.20±0.53	0.14	0.29	p>0.050
Lead (mg/L)	0.02±0.01	0.02	0.03	0.04±0.02	0.02	0.06	p<0.500
Iron(mg/L)	0.19±0.45	0.06	0.54	2.62±0.95	1.72	4.40	p<0.001
Manganese (mg/L)	0.07±0.03	0.03	0.15	0.18±0.05	0.13	0.28	p<0.050
Zinc (mg/L)	0.23±0.07	0.14	0.34	0.33±0.09	0.18	0.49	p<0.001

NB: p<0.05 specifies significant difference; p<0.001 specifies highly significant difference; p>0.05 specifies no significant difference

Water Temperature

Water temperature ranged from 25.00-28.00°C in the stations studied. The highest mean water temperature of 26.33±1.21°C was observed in stations 1 and 3 while the lowest was observed in station 2 with a mean temperature of 25.83±1.47°C There was no significant difference (p>0.05) between the average water temperatures of the three stations (Table 1a). A highly significant seasonal variation (p<0.001) was obtained as the values for water temperature recorded during the dry season were higher than the values obtained during the wet season (Table 1b).

Air Temperature

The mean air temperatures of 30.50±1.87, 30.17±2.71 and 30.00±1.90°C were the values recorded in stations 1, 2 and station 3. There was no significant difference (p>0.05) observed in the average air temperature values from the three stations, but a highly significant seasonal variation was observed as higher air temperature values were documented in the dry period (32.00°C) than what was recorded in the wet period (28.44°C) (Table 1b).

Hydrogen Ion Concentration (pH)

All the stations studied had almost the same pH ranges with mean values of 6.48±0.47, 6.43±0.56 and 6.35±0.4 in stations 1, 2 and 3 respectively. There was no significant difference ($p>0.05$) between the mean pH values in the three stations. There was however a highly significant ($p<0.001$) seasonal variation as mean pH values of 6.00±0.12 and 6.88±0.10 were observed in the dry as well as wet seasons respectively (Table 1b).

Electrical Conductivity (EC)

The mean EC value ranged from 46.67±19.66 µS/m in station 1-50.00±21.91 µS/cm in stations 2-3 (Table 1a). There was no observed significant difference ($p>0.05$) between the average electrical conductivity levels in the three stations. Mean electrical conductivity values of 30.00±7.07 and 67.78±6.67 µS/cm were observed in dry and wet seasons respectively. Thus, a highly significant seasonal variation ($p<0.0001$) was observed between the electrical conductivity of the two seasons (Table 1b).

Turbidity

The mean Turbidity values ranges were 10.33±3.88 NTU in station 1 and 12.33±3.78 NTU in station 2. There was no observed significant difference ($p>0.05$) among the average turbidity values from the three stations. In the dry season months, a mean turbidity value of 8.67±1.94 NTU was observed which was lower than the 14.56±3.21 NTU value recorded in the wet seasons. This difference was significant at $p<0.05$ (Table 1b).

Suspended Solids (SS)

The mean SS value of 6.00±3.03 mg/L was observed in station 1, while 8.17±2.14 mg/L was documented in station 2 and 10.00±4.43 mg/L was recorded in station 3 (Table 1a). There was no observed significant difference ($p>0.05$) between the average suspended solids values from the three stations. The average values of 5.78±2.11 and 10.33±3.28 mg/L were observed in dry and wet seasons individually. There was however significant ($p<0.05$) seasonal variation between the wet and dry seasons (Table 1b).

Total Dissolved Solids (TDS)

The mean TDS concentration value of 24.73±10.42 mg/L was documented in station 1, while 25.62±12.73 mg/L was documented in station 2 and 26.50±12.54 mg/L was documented in station 3. There was no observed significant difference ($p>0.05$) between the average TDS values of the three stations (Table 1a). In the dry season months, the mean TDS value of 15.31±4.14 while 35.92±3.53 mg/L was documented in the wet period thus showing a highly significant ($p<0.001$) seasonal variation between the mean TDS values in the wet and dry season (Table 1b).

Dissolved Oxygen (DO)

The mean DO values of 6.45±0.93, 6.28±1.30 and 6.02±1.04 mg/L were observed in stations 1, 2 and 3 respectively. There was no observed significant difference ($p>0.05$) between the mean values of DO levels from the three stations (Table 1a). The mean dissolved oxygen value of 5.60±0.67 mg/L was recorded during the dry season while the mean value of 6.90±0.97 mg/L was noticed during the wet period, which therefore showed a significant difference ($p<0.05$) (Table 1b).

Biochemical Oxygen Demand (BOD_5)

The average BOD_5 value of 2.30±1.21 mg/L was observed in station 3 while 3.15±1.10 mg/L was noticed in station 1 and 2.73±1.55 mg/L value was documented in station 2 correspondingly. There was no observed significant difference ($p>0.05$) between the mean BOD_5 ranges among the three stations (Table 1a). During the dry period, a mean BOD_5 value of 2.01±1.14 mg/L was observed while 3.44±1.00 mg/L was observed in the wet period. A significant ($p<0.05$) seasonal dissimilarity was however noticed between the mean BOD_5 value in both the dry as well as the wet seasons (Table 1a).

Alkalinity

The mean alkalinity values of 24.67±6.41 mg/L were documented in station 1 while 24.00±5.22 mg/L was documented in station 2 and 23.67±8.52 mg/L in station 3 accordingly (Table 1a). There was no observed significant difference between the average alkalinity values from stations 1, 2 and 3. Mean values of 26.44±8.41 mg/L were noticed during the dry period while the value of 21.78±2.33 mg/L was documented during the wet period. There was no observed significant ($p>0.05$) seasonal variation between the mean alkalinity values from both wet and dry seasons (Table 1b).

Calcium (Ca)

The mean Ca values of 10.69±6.70 mg/L were recorded in station 1, while 8.82±6.45 mg/L was documented in station 2 and 10.82±6.83 mg/L was noticed in station 3. There was no observed significant difference ($p>0.05$) among the mean calcium values in the three stations (Table 1a). A mean calcium value of 5.43±2.03 mg/L was documented during the dry period while 14.79±5.64 mg/L was recorded during the wet season. Therefore, it shows a highly significant ($p<0.01$) seasonal variation from both seasons (Table 1b).

Magnesium (Mg)

The mean magnesium values observed were 2.19±1.26 mg/L in station 1, 3.41±1.95 mg/L in station 2 and 2.92±1.38 mg/L in station 3. There was no observed significant difference ($p>0.05$) among the mean magnesium levels in the three stations (Table 1a). A Mean magnesium value of 2.32 mg/L was observed during the dry season while 3.35 mg/L was recorded during the wet season with no observed significant ($p>0.05$) seasonal variation (Table 1b).

Sulfate (SO_4)

The mean SO_4 concentrations of 8.83±7.60, 8.67±7.37 and 10.67±6.98 mg/L were observed in stations 1, 2 and 3 respectively. There was no observed significant difference ($p>0.05$) among the mean sulfate concentrations for the three stations (Table 1a). During the dry season, a mean sulfate value of 15.89±2.42 mg/L was observed while a very low value of 2.89±1.17mg/L was observed in the wet season. A highly significant seasonal variation ($p<0.001$) was observed between the sulfate concentrations in both seasons (Table 1b).

Nitrate (*NO_3*)

The NO_3 mean values ranged from 1.66±0.83 mg/L in station 2-2.18±0.89 mg/L in station 3. There was no observed significant variance in the mean nitrate values from all three stations (Table 1a). The mean nitrate concentration of 1.31±0.85 mg/L was observed during the dry season while 2.57±0.31 mg/L was documented during the wet period with no observed significant ($p<0.05$) seasonal variation (Table 1b).

Phosphate (*PO_4*)

Very little variation was observed in the mean PO_4 levels of the three stations with average values of 0.24±0.04 mg/L for stations 1 and 2 and 0.28±0.04 mg/L for station 3 (Table 1a). There was no observed significant difference (p>0 05) between the average phosphate values from the 3 stations. There was no observed significant seasonal variation ($p>0.05$) in both seasons as the average concentration value of 0.25±0.04 mg/L was documented in both seasons (Table 1a).

Chloride (*Cl*)

The average Cl values of 16.47±5.75, 17.65±3.87 and 15.30±2.89 mg/L were observed for stations 1, 2 and 3 respectively. There was no observed significant difference ($p>0.05$) in the mean chloride values from the three stations (Table 1a). The mean Cl concentrations of 15.69±3.11 and 17.26±5.1 2 mg/L were observed in dry and wet seasons respectively. There was no observed significant difference in average chloride values in both seasons (Table 1b).

Hardness

The mean value of hardness ranged from 35.33±17.28 and 36.00±19.06 mg/L in station 1 and 2-38.67±16.28 mg/L in station 3. There was no observed significant difference ($p>0.05$) between the mean concentrations of the hardness of the water in the three stations (Table 1a). A high variation was observed in the average hardness concentration in the dry and wet periods as a mean hardness of 22.89±6.49 mg/L was recorded during the dry season while a mean hardness of 50.44±10.71 mg/L was documented during the wet period thus showing a highly significant seasonal variation ($p<0.001$) (Table 1a).

Copper (*Cu*)

The mean Cu concentrations were similar in stations 1 and 2 recordings of 0.25±0.07 mg/L in station 1, then 0.26±0.09 mg/L in station 2. While copper means the value of 0.32±0.12 mg/L was recorded in station 3. There was no observed significant difference ($p>0.05$) in the average copper concentrations from all stations sampled (Table 1a). The average copper level of 0.46±0.08 mg/L was recorded during the dry period while the mean value of 0.20±0.53 mg/L was recorded during the wet season, there was no observed significant difference ($p>0.05$) in the seasonal variation (Table 1b).

Lead (*Pb*)

The mean Pb concentration of 0.03±0.02 mg/L was detected in stations 1 and 2 with minimal deviations in station 3, with a mean value of 0.03±0.01 mg/L. There was no observed significant difference ($p>0.05$) in the mean lead concentrations from all the stations sampled (Table 1a). The average concentration level observed during the dry season was 0.02±0.01 mg/L while 0.04±0.02 mg/L was recorded in the wet period, with observed significance at ($p<0.05$) (Table 1b).

Iron (Fe)

The mean Fe level recorded in station 1 was 1.11±1.10, while 1.61±1.66 mg/L was recorded at station 2 and 1.50±1.64 mg/L at station 3. There was no observed significant difference ($p>0.05$) in iron average concentrations in the three stations sampled (Table 1a). A highly significant seasonal variation ($p<0.001$) was recorded between mean concentrations of iron, with a value of 0.19±0.45 mg/L recorded during the dry season while 2.62±0.95 mg/L was documented throughout the wet period (Table 1b).

Table 2: Summary of HMs (Heavy metals) levels in the tissues of *Chromidotilapia guntheri*

Parameters in mg/kg	Mean ± SD	Min	Max
Cu	0.779±0.522	0.204	1.282
Pb	0.163±0.053	0.109	0.242
Fe	6.825±3.730	4.318	12.344
Mn	0.824±0.803	0.077	1.772
Zn	0.355±0.062	0.264	0.425

Table 3: Periodic difference in HMs levels in tissue of *Chromidotilapia guntheri*

The parameter in mg/kg	Dry season			Wet season			
	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Sig
Cu	0.19±0.03	0.14	0.240	0.14±0.19	0.11	0.20	p<0.05
Pb	0.35±0.05	0.26	0.430	0.36±0.05	0.33	0.43	p>0.05
Fe	9.70±3.10	6.29	12.34	3.95±0.63	3.22	4.32	p>0.05
Mn	1.15±0.89	0.13	1.77	0.50±0.71	0.08	1.32	p>0.05
Zn	1.24±0.08	1.22	1.28	0.32±0.05	0.20	0.54	p>0.05

Table 4: Bioaccumulation factors of HMs in *C. guntheri* from the Ada River

HMs	BAF
Pb	5.26
Zn	1.10
Fe	4.85
Mn	6.34
Cu	2.81

Table 5: Risk evaluation for the ingestion of *Chromidotilapia guntheri* from Ada River

HMs	Non-carcinogenic indices EDI	THQ	% Influence of HMs on HI
Mn	0.339	0.024	19.000
Zn	0.146	0.000	0.000
Pb	0.067	0.019	15.000
Fe	2.810	0.004	3.000
Cu	0.321	0.080	63.000
HI		0.127	No Risk

Manganese (Mn)

There was slight dissimilarity in the average concentration of Mn observed in the three stations. A mean value of 0.13±0.09 mg/L was documented in station 1 while 0.11±0.06 mg/L was documented in station 2 and 0.14±0.06 mg/L in station 3. There was no observed significant difference (p>0.05) between manganese average concentrations in all the stations sampled (Table 1a). The mean concentration value of 0.07±0.03 mg/L was recorded during the dry season while 0.18±0.05 mg/L was documented during the wet period, thus showing a significant (p<0.05) seasonal variation (Table 1b).

Zinc (Zn)

There was a little variation in the average level of Zn from the three stations as mean values of 0.36±0.19, 0.31±0.11 and 0.31±0.15 mg/L were recorded in stations 1, 2 and 3 respectively. There was no observed significant difference in the average zinc level in all the stations sampled (Table 1a). However, a highly significant seasonal variation (p<0.001) was observed as the mean concentration of 0.23±0.07 mg/L was recorded during the dry season while 0.33±0.09 mg/L was recorded during the wet seasons (Table1b).

Summary of the Mean Concentration of Metals in the Tissues of Chromidotilapia guntheri

The average concentrations of Zn, Mn, Fe, Pb and Cu in the muscles of *Chromidotilapia guntheri* were 0.355±0.062, 0.824±0.803, 6.825±3.730, 0.163±0.053 and 0.779±0.522 mg/kg individually (Table 2).

The average concentrations observed in the dry and wet seasons from the level of Zn, Mn, Fe, Pb and Cu in the tissues of *Chromidotilapia guntheri* were 1.24±0.08 and 0.32±0.05 mg/kg, 1.15±0.0.89 and 0.50±0.71 mg/kg, 9.70±3.10 and 3.95±0.63 mg/kg, 0.35±0.005 and 0.36±0.05 mg/kg and 0.19±0.03 and 0.14±0.19 mg/kg correspondingly (Table 3).

There was no significant difference (p>0.05) in the seasonal variation of Zn, Mn, Fe and Pb. However, Cu displayed a significant variation in both seasons. The HMs in *Chromidotilapia guntheri* varied in this progression; Mn> Pb > Fe > Cu> Zn correspondingly.

(BAF) Bioaccumulation Factor of C. guntheri

Table 4, the BAF of the HMs concentrations in *Chromidotilapia guntheri* were all >1.

Non-Carcinogenic Assessment of Metals in Chromidotilapia guntheri Tissue

Table 5 shows the risk evaluation for the ingestion of *Chromidotilapia guntheri* sourced from Ada River. The results show that the progression of HMs for the EDI evaluation is Fe>Mn> Cu> Zn > Pb. Meanwhile, the progression of HMs from THQ evaluation is Cu >Mn > Pb >Fe > Zn. Both assessments had values <1 with the exception of Fe which had a value >1. In addition, the HI value was <1. The possible percentage of influences of the studied HMs showed that Mn, Pb and Cu may likely have a high percentage contribution to the HI.

Discussion

Physical and Chemical Characteristics of Ada River

From this study, the water and air temperatures showed similar trends both at the spatial and seasonal levels. This might be linked to the tropical nature of the river because it is closer to the Atlantic Ocean (Awachie, 1981; Anani *et al*. 2020; Anani and Olomokuro, 2021).

The pH values documented in this study fall within acceptable limits. The quality of the water was within the acidic-neutral level. This reveals a good quality of water as reported by Fakayode (2005). Similar findings have also been reported by Martin *et al*. (1998), Izonfuo and Bariweni (2001); Anani *et al*. (2020). In addition, the pH values obtained in this study are quite higher than the ranges (5.76-6.01) observed by Ikhouriah and Oronsaye, (2016) for the Ologbo River and 5.53-5.75 for the Iguedo River reported by Udebuana *et al*. (2014). Ringim (2015) recorded higher ranges of 6.82-8.18 (rainy season) and 6.98-7.67(dry season) for the Challawa River, Kano state. The pH values obtained in this study are quite higher than the ranges (5.76-6.01) observed by Ikhouriah and Oronsaye (2016) for the Ologbo River and 5.53-5.75 for the Iguedo River reported by Udebuana *et al*. (2014). These high pH values might be attributed to the high level of carbonate-rich soil (carbonate and bicarbonate) in Udebuana *et al*. (2014). Ringim (2015) recorded higher ranges of 6.82-8.18 (rainy season) and 6.98-7.67 (dry season) for the Challawa River, Kano state. A good pH is a determining factor of other chemical actions like metal noxiousness and solubility of dissolved materials in water.

The electrical conductivity recorded in this study was fair compared to what was obtained in previous studies like the values reported for the Siluko River by Ekhator (2010); Oboh and Agbala (2017); Utor River (42.51-59.7 µs/m) and Ogba River (40.8-50.6S µs/m) reported by Ogbeibu and Anagboso (2004); Anyanwu (2012), respectively. However, it was lower than the range of 14.50-155.23 µs/m) for the Eruvbi stream (Imoobe and Koye, 2011). In addition, the values were fairly low relative to the (WHO, 2011a; NSDWQ, 2007) standard thresholds for drinking water.

In this study, the turbidity values recorded for the spatial and seasonal regimes fall below the (WHO, 2011a; NSDWQ, 2007) standard thresholds for drinking water. However, there was a fluctuation in the rainy season because of the presence of TSS and SS due to the run-offs. Similar values of turbidity (7.30-11.07 NTU) were reported by Ayanwu (2012) for the Ogba River and 11.58-21.61 NTU for the Keffi River by Adewumi *et al*. (2014). Nonetheless, Ikhouriah and Oronsaye reported low ranges of 3.97-4.37NTU for the Siluko River while higher ranges of turbidity (110-136 NTU) and (9.47-468.18 NTU) were reported by Ekhaise and Anyasi (2005); Edjere *et al*. (2016) respectively for the Ikpoba River by the Guinness brewery and (Anani *et al*., 2020) reported a minimum and maximum values of 3.93 and 5.54 NTU at Ossiomo River.

It was noticed that the values of the SS recorded in this study had similar values of turbidity (7.30-11.07) (NTU) as reported by Ayanwu (2012) for the Ogba River and 11.58-21.61NTU for the Keffi River by Adewumi *et al*. (2014). However, Ikhouriah and Oronsaye reported low ranges of 3.97-4.37NTU for the Siluko River while higher ranges of turbidity (110-136NTU) and (9.47-468.18 NTU) were reported by Ekhaise and Anyasi (2005); Edjere *et al*. (2016) respectively for the Ikpoba River by the Guinness brewery. Meanwhile, the TDS values documented in this river were similar to the 33.84-29.6 and 27.66-30.11 mg/L that were reported by Ikhuoriah and Oronsaye, (2016); Anyanwu (2012) for the Siluko and Ogba Rivers respectively. Oboh and Agbala (2017) reported higher ranges (50.73-57.83 mg/L) for the Siluko River. A TDS value of 90.60 mg/L at Ossiomo River., was reported by Anani *et al*. (2020). The findings from this study show that the SS and TDS fall below the (WHO, 2011a; NSDWQ, 2007) standard thresholds for drinking water.

The DO values recorded in this study showed that they were fairly higher than the National Standard for Drinking Quality Water (NSDWQ, 2007) standard thresholds. Similar dissolved oxygen ranges for the Iko River 5.6-8.42 mg/L and Ossiomo River 7.12-7.54 mg/L were reported by Ikhuoriah and Oronsaye (2016) respectively and 5.67 mg/L and 6.23 mg/L by Anani and Olomukoro (2021) at Ossiomo River. Lower dissolved oxygen ranges of 1.84-5.22 and 1.81-3.29 mg/L were reported individually by Ogbeibu and Edutie (2002); Edjere *et al*. (2016). Imoobe and Koye (2011) also recorded low DO values (2.2-4.8 mg/L) at the effluent discharge point along the Eruvbi stream which showed poor aeration of the water body due to effluent discharge. Low DO can result in death due to the competition of the limited volume. This becomes a critical resource and reduces the quality of the water.

The BOD_5 values documented in this study fall below the (WHO, 2011b) and National Standard for Drinking Quality Water (NSDWQ, 2007) standard thresholds (5.00 mg/L). Similar BOD_5 ranges were also reported by Ringim (2015) from the Challawa River and Udebuana *et al*. (2014) for the Iguedo River. Nonetheless, (Imoobe and Koye, 2011) reported a higher BOD_5 of 18.47 mg/L for the Eruvbi stream. The findings of this study showed that this is an indication that water is between the unpolluted and good quality levels of specified standards.

The mean alkalinity values recorded in this study were noticed to be far lower than what was reported by Anyanwu (2012); Ikhouriah and Oronsaye (2016) for the Ogba River (35.08-50.33 mg/L) and the Ossiomo River (48.63-53.28 mg/L) respectively. However, the values were far higher than the 2.44±1.11 mg/L reported by Anani and Olomukoro, (2021) in a different stretch of Ossiomo River.

The mean Ca content in Ada River was relatively low when compared with the standard limits. This can be compared with the 1.11-9.62 mg/L by Omoigberale and Ogbeibu (2007) for the Osse River but higher values have also been documented in some water bodies in Nigeria. Ogbeibu and Edutie (2002) recorded a range of 4.80-25.0 mg/L in Ikpoba River and Ibadin (2006) documented values of 0.40-19.24 mg/L for Utor River. Anyanwu (2012) reported similar values of 11.79-12.92

mg/L for the Ogba River. The mean value obtained in Ada River might not be unconnected with its natural occurrence in the water body. Similarly, the Mg values recorded in Ada River fall within the recommended thresholds of the regulatory bodies used in this study.

The mean SO_4, NO_3 and PO_4 values documented in Ada River fall within the recommended thresholds of the regulatory bodies used in this study. Lower sulfate concentrations have been reported by previous researchers; 0.32-6.06 mg/L for the Ogba River by Anyanwu (2012), 0.32-0.34 mg/L for the Calabar River by Nnamani *et al*. (2015) and 0.8 4.8 mg/L for Okhuo River by Imoobe and Koye (2011). Reported a very high sulfate concentration of 170.8-270.6 mg/L for the Iko River. For NO_3 and PO_4, (Anani *et al*., 2020); Anani and Olomukoro, 2021) reported 1.55- 2.96 and 0.651.27 mg/L for Ossiomo River respectively. In addition, various phosphate values also had been documented; 0.17 l-0.59 mg/L in Ossiomo River, Awana (2002), 0.26-1.90 mg/L in Utor River, Emu, Edo state, Udebuana *et al*. (2014), 0.63-0.81 mg/L in Iguedo River. Omoigberale and Ogbeibu (2007) documented fairly high values of 0.28-3.52 mg/L for the Osse River.

The Cl concentration observed in Ada River also falls within the recommended thresholds of the regulatory bodies used in this study. This depicts that the Ada River is in freshwater form. The values were comparatively the same as what was reported in River Ogba, Ologe Lagoon and Osse, Owo Rivers (Anyanwu, 2012; Yusuf and Osibanjo, 2007, Omoigberale and Ogbeibu, 2007). Moreso, the values of the total hardness recorded in Ada River, fall within the recommended thresholds of the regulatory bodies used in this study. Ringim (2015) reported similar ranges (46.88-66.80 mg/L) in the rainy period and slightly higher ranges (41.11-92.09 mg/L) in the dry period of the Challawa River in Kano state, Nigeria. It was noticed that most of the heavy metals were from geogenic and human activities like chemicals for farming.

Heavy Metal Concentration in the Water

It was observed that the heavy metal concentrations in Ada River fell within the recommended thresholds of the regulatory bodies used in this study. The relatively low Cu documented in this study may be a result of low domestic, activities from humans and lithogenic inputs (Anani *et al*., 2020; Anani and Olomukoro, 2021). The observed Pb concentration was similar to what was reported for the Owan River (0.005 mg/L) and River Niger at Agenebode (0.007 mg/L) by Omoigberale *et al*. (2014); Wangboje and Ikhuabe, (2015) respectively while (Omoregie *et al*., 2016) reported a higher mean value (0.44 mg/L) for the Osse River. Similarly, the Zn concentration documented in this study fell within the ranges reported for the Ikpoba River Dam 0.07-0.96 mg/L, River Niger at Agenebode 0.15-0.35 mg/L, the Antau River, Keffi (0.30-1.30 mg/L) by Oronsaye *et al*. (2010); Wangboje and Ikhuabe (2015); Adewumi *et al*. (2014) respectively. The concentration of Fe documented in this study for Ada River was similar to ranges (0.59-1.12 mg/L) and (0.413-0.810 mg/L) documented by Enuneku *et al*. (2013); Omoigberale *et al*. (2014) respectively for Owan River. In contrast, Fufeyin (1998); Abolude *et al*. (2013) reported higher ranges (2.00-7.00) and (4.75-5.98 mg/L) of Iron in the water of Ikpoba River and the Bindare Stream, Sabon Gari, Zaria respectively. The Mn concentration documented in this study was also similar to the 0.001-0.002 mg/L reported by Obasohan (2021) for the Ogba River and (Nwani *et al*., 2010) reported 0.400-0.490 mg/L for the Afikpo River. Zn noxiousness is rare, but levels up to 40 mg/kg in environmental media pose a potential risk for health conditions like muscular pains, stiffness and retard irritability (Akan *et al*., 2012; Enuneku *et al*., 2018a; 2019; 2021).

Heavy Metal Concentration in Chromidotilapia Guntheri

In this study, the mean Cu concentration in the tissue of *Chromidotilapia guntheri* was observed to be far below the 3.0 mg/kg threshold set by WHO (2011a). A similar report was recorded by Eneji *et al*. (2011) 1.6 5 mg/kg of Cu in *Tilapia zilli* from River Benue and (Nwani *et al*., 2010) reported 1.33 mg/kg in Afikpo River. Contrary, (Obasohan, 2021) reported 3.82 mg/kg of Cu in *Hemichromis fasciatus* from Ogba River in Benin City. Copper has been identified as a major element and a cofactor in the physiology of enzymes in living organisms when present at a level that it will not cause toxicity.

The concentration of Pb present in the tissue of *Chromidotilapia guntheri* was found to be below the standard limit of 0.5 mg/kg set by the (WHO, 2008). Ezemonye and Egborge (1992); Oguzie (2003) reported similar findings of 0.13 mg/kg (*H. fasciatus*) and 0.007-0.03 mg/kg (fishes) from the Warri River and Ikpoba River correspondingly. Meanwhile, 2.67-7.33 mg/kg was reported by Obasohan (2007) *Parachana obscura* from Ogba River. Lead (Pb) noxiousness is linked to developmental, reproductive, immunological, neurological, ocular, renal and musculoskeletal effects in living things (Anani and Olomukoro 2018a; Enuneku *et al*. 2018a; Anani and Olomukoro, 2019).

The mean Fe concentration recorded in this study was very low when linked to the 8.01, 7.38 and 7.37 mg/kg documented for *T. zilli* by Eneji *et al*. (2011); Modibbo *et al*. (2014); Nwosu *et al.* (2014) from River Benue, Lake, Yola

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River and Oguta Lake respectively.

In this study, the Mn concentration recorded was observed to be slightly higher than the (FEPA, 2003; WHO, 2011b) standard limits in the tissue of living vertebrates. The value obtained can be compared favorably to what was obtained at 0.71 and 1.07 mg/kg by Ezemonye and Egborge (1992); Fufeyin (1998) at Warri and Ikpoba Rivers respectively. This high concentration could be linked to human activities such as agriculture in the region where the fish species were sampled. However, Oguzie (2003) reported a low concentration (0.315 mg/kg) of Mn from the Ikpoba River. The pathway in which Mn could have entered the fish is via the gills and muscles. This could pose serious toxicity when ingested in a concentration higher than the safe limit.

The concentration of Zn obtained in this study in *Chromidotilapia guntheri* was lower than what was obtained at 5.24, 3.84 and 3.52 mg/kg in *T. zilli* by Eneji *et al*. (2011); Modibbo *et al*. (2014); Nwosu *et al*. (2014) respectively. It was also found to be within the safe limits of 30 mg/kg established by Nauen (1983).

BAF Concentration of Heavy Metals in Chromidotilapia guntheri

The BAF values detected in *Chromidotilapia guntheri* display that the fish bioaccumulated toxic metals from the superficial water as the concentration in the fish was higher than the concentrations in the water. A similar report by Anani and Olomukoro (2019) was also reported in Ossiomo River, Nigeria on related aquatic species.

Possible Non-Carcinogenic Health of Heavy Metals in Chromidotilapia guntheri

The results obtained from the non-carcinogenic risks (HI, THQ and EDI) showed that the concentrations of the heavy metals were <1. This means that there are no possible non-carcinogenic risks from the ingestion of the metals in the tissues of *Chromidotilapia guntheri*. Similar reports have been documented by Abdou and Hassan (2014); Enuneku and Adelusi (2015); Anani and Olomukoro (2018a).

Conclusion

This study evaluated the water characteristics, bioaccumulation and non-carcinogenic risk potentials in the ingestion of toxic metals like Cu, Fe, Zn, Mn and Pb in *Chromidotilapia guntheri* from Ada River. The findings from the river water parameters showed fluctuations statistically at the spatial level ($p>0.05$) for all the physical and chemical parameters and seasonal $p<0.001$ (highly significant) for DO, BOD_5, Ca, Mg, NO_3, PO_4, Cl, Cu, Pb and Mn and $p<0.05$ (significant) for water temperature, air temperature, pH, EC, TDS, Alkalinity, SO_4, hardness, Fe and Zn correspondingly. Similarly, the seasonal variations of heavy metals in the fish tissues showed that there was a significant difference ($p<0.05$) in Cu for both the wet and dry periods. However, a non-significant difference ($p>0.05$) existed in Pb, Fe, Mn and Zn for both seasons. The results obtained from this study showed that the analyzed metals have BAFs (Bioaccumulation Factors) >1 which was also greater than the concentrations in water. The HMs in *Chromidotilapia guntheri* varied in this progression; Mn> Pb > Fe > Cu> Zn correspondingly. The results of the Hazard Index (HI) 0.127 of *Chromidotilapia guntheri* showed that all the metals were less than the threshold value of 1. The results of the THQ (Target Hazard Quotient) showed the variations of the metals as Cu (0.040)> Mn (0.014)> Pb (0.002)> Fe (0.000)> Zn (0.000) correspondingly. More so, the results of the EDI (Estimated Daily Intake) showed the following rank pattern Fe>Mn> Cu> Zn > Pb. The low values (<1) observed for the HI, THQ and EDI, indicate that the species of fish is good for human ingestion in this current period of study. The possible percentage of influences of the studied HMs showed that Mn, Pb and Cu may likely have a high percentage contribution to the HI. However, the high value (>1) observed in the BAFs of metals, showed possible non-carcinogenic concern. The results obtained from the non-carcinogenic risks (HI, THQ and EDI) showed that the concentrations of the heavy metals were <1. This means that there are no possible non-carcinogenic risks from the ingestion of the metals in the tissues of *Chromidotilapia guntheri*. We recommend continuous monitoring of the Ada River to ascertain the trend of bioaccumulation and regulate the possible activities causing this effect.

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Author’s Contributions

Tunde Ohiokhioya Thaddeus Imoobe: Contributed to the research design, data collected, data analysis, written, edited and reviewed this manuscript.

Supervised the research. Gave final approval for the submission of the manuscript.

Eugene Iragboghie Okhakhu: Contributed to the research design, data collection, data analysis, written, editted and review of this manuscript. Gave final approval for the submission of the manuscript.

Osikemekha Anthony Anani: Contributed to the research design, data collection and data analysis, written, edited and reviewed this manuscript. Gave final approval for the submission of the manuscript.

Data Availability Statement

Data will be made available on request.

Conflict of Interest

We declare no financial conflict of interest amongst us.

Declarations

All authors have read, understood and have complied as applicable with the statement on "ethical responsibilities of authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

Ethics

There are no future ethical issues the authors foresee happening to the publication of the manuscript. The authors all approved the final submission of this study.

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