



# Heavy metal content and health risk assessment of a South-eastern Nigeria River

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## Abstract

An enormous deficiency lag exists in the demand and supply of potable water in Umuahia, Abia State, Nigeria. The people have to pay lots of money to get potable water from water vendors, and those who cannot afford to pay patronize other unwholesome sources. Ossah River, one of the local drinking water sources, was studied to assess the heavy metal content and health risk assessment vis-a-vis its suitability for human consumption. Eight (8) heavy metals (Mn, Cu, Pb, Fe, Zn, Cd, Cr and Ni) were assessed between January and June 2018 in 3 stations, using atomic absorption spectrometer, and compared with Nigerian drinking water standards. Some of the heavy metals evaluated exceeded standards and warranted health risk assessment. Health risk assessment for all the stations indicated that there is no particularly dangerous single heavy metal, but their cumulative effect, indicated by the hazard index (HI). HI for all the stations highly exceeded threshold value (1). This calls for concern for both adults and children exposed to the water through ingestion. The heavy metal contamination observed was geogenic, exacerbated by anthropogenic activities.

**Keywords** River · Heavy metal · Effluent · Anthropogenic · Limits

## Introduction

Rivers is one of the most important freshwater resources, and most developmental activities are dependent upon them (Al Obaidy et al. 2015). Surface waters like lakes, rivers and streams and groundwater like springs and well waters usually serve as sources of drinking water. Rivers in a watershed play a major role in assimilating or carrying off municipal and industrial wastewater and runoff from agricultural land (Wang et al. 2007). Industrialization is considered a necessity for the development of a country's economy, through the establishment of plants and factories (Ho et al. 2012). However, the waste or by-products discharged from them are destructive to the environment; contaminating the surface water, ground water and soil (Adakole 2011). The wastewaters are not safely treated because of the lack of highly efficient and economic treatment technology (Ho et al. 2012) and failure in institutional monitoring and control.

The term “heavy metals” refers to any metallic element that has relatively high density and applies to the group of metals and metalloids with atomic density greater than  $5 \text{ g cm}^{-3}$  (Oves et al. 2012). Some of them are essential elements without which the biochemical processes in living organisms would not be possible; however, when they exceed normal concentrations, they become harmful to organisms (Goorzadi et al. 2009; Bytyçi et al. 2018). Heavy metal pollution of soil and water has become one of the main concerns of human beings recently (Namaghi et al. 2011) and is often associated with variables of concealment, persistency and irreversibility (Zhu et al. 2012). Heavy metals occur naturally in rocks, but most of the heavy metals occurrences originate from anthropogenic sources (Obaroh et al. 2012).

Heavy metals may contaminate the surface water, springs and groundwater resulting in deterioration of drinking water quality. Heavy metal pollution in water can be assessed by measuring their concentrations (Senarathne and Pathiratne 2007). Chima et al. (2009) observed an enormous deficiency lag in demand and supply of potable water in Umuahia, Abia State, Nigeria. The observed deficiency manifests in poor social life of the people as well as in the various health problems associated with it (Nghah and Abam 2016). The people

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have to pay lots of money to get potable water from water vendors, and those who cannot afford to pay patronize other unwholesome sources (Chima et al. 2009).

Ossah River is an urban river that receives industrial effluent from a vegetable oil processing factory and also subjected to other anthropogenic impacts. It is used by the communities for drinking, bathing, washing, swimming and other domestic activities. This study was aimed at assessing the heavy metal content and health risk assessment of Ossah River vis-a-vis its suitability for human consumption.

## Description of study area

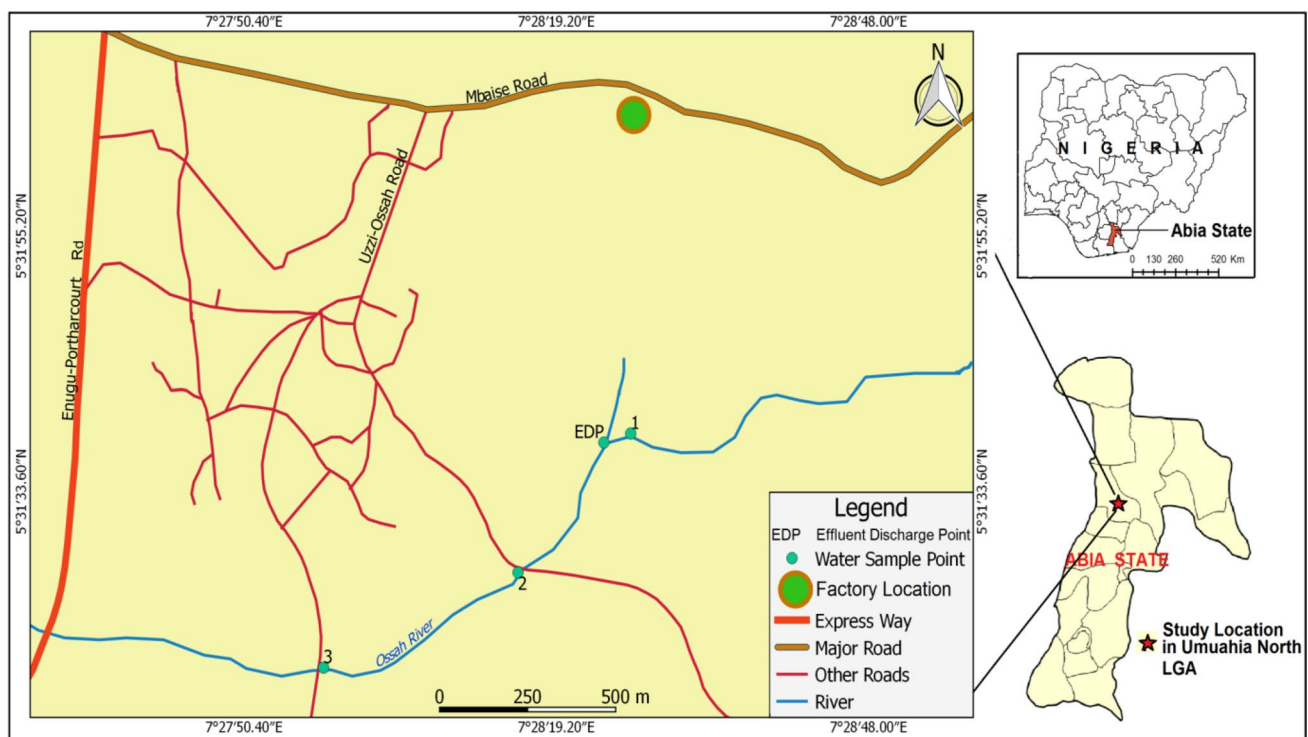
The study was carried out in Ossah River located in Umuhia, South-east Nigeria. The section of the river studied lies within latitude  $05^{\circ}29'20.00''$ – $05^{\circ}31'40.00''$  N and longitude  $07^{\circ}27'50.40''$ – $07^{\circ}28'54.80''$  E (Fig. 1). Station 1 is upstream and control station, located in Ahi Amanso, Ossah community. There is a lot of building and road construction activities going on in the watershed; stormwater from the sites discharge into the river. The station is relatively deep and the substrate is sandy. Other activities observed in the station include sand mining, bathing, swimming, washing of clothes, extraction of water for drinking. Occasional human defecations were also observed around the river. Station 2 is located at Eziamia Ossah, 510 m downstream of Station 1 and 410 m downstream of the effluent discharge

point (EDP). It is shallow and sandy with minimal activities like washing, bathing and periodic watering of cattle. This station was abandoned as a drinking water source because of the effluent discharge. Station 3 is located at Umuchime Ossah, 610 m downstream of Station 2. The station is by a bridge along an abandoned road construction site. The station was deep with a sandy substrate. Stormwater also discharge into this station during the rains, depositing sand on the edge of the river. Human activities were observed during the study including extraction of water for drinking, fishing, bathing, swimming, washing of motorcycles, tricycle (keke) and clothes.

## Methodology

### Samples collection and analyses

Water samples were collected from Ossah River monthly from January to June 2018. The samples were collected with a 1 litre water sampler, transferred into a clean 250-ml plastic bottle and acidified with nitric acid ( $\text{HNO}_3$ ) according to Sharma and Tyagi (2013). The water samples were digested using concentrated Analar nitric acid according to Zhang (2007). The UNICAM Solaar 969 atomic absorption spectrometer (AAS) which uses acetylene-air flame was used for the determination of heavy metals. All the results were



**Fig. 1** Map of Umuhia, Abia State, Nigeria, showing the sampling stations of Ossah River

statistically analysed using single-factor ANOVA, and Tukey pairwise test was performed to determine the location of significant difference.

### Health risk assessment

Health risk assessment was carried out for the metals that exceeded acceptable limits (Fe, Mn, Zn, Cd and Cr). The human health risk assessment method used in this study was for non-carcinogenic as described by Muhammad et al. (2011). The chronic daily intake (CDI) of heavy metals in Ossah River water was evaluated by the equation:

$$CDI = \frac{C_w \times IR \times EF \times ED}{B_w \times AT} \tag{1}$$

where CDI is the daily dose of heavy metals (mg/l) to which consumers might be exposed. CW (mg/l) is the concentration of heavy metals in the river water, IR is the ingestion rate, EF is the exposure frequency, ED is the exposure duration, BW is the body weight, and AT is the averaging time. The input parameters used in evaluating CDI values are presented in Table 1.

### Hazard quotient (HQ)

The HQ for non-carcinogenic risk was calculated using the equation by USEPA (1999)

$$HQ = \frac{CDI}{RfD} \tag{2}$$

where CDI is the daily dose of heavy metals (mg/l) to which consumers might be exposed and RfD is the reference dose which is the daily dosage that enable individual to sustain this level of exposure over a long period of time without experiencing any harmful effects. The oral toxicity reference dose (RfD) values for the heavy metals are presented in Table 2:

If  $HQ > 1$ , it represents adverse non-carcinogenic effects of concern, while  $HQ < 1$  represents acceptable level (no concern).

**Table 1** Input parameters to characterize CDI values

Factor/parameter	Symbol	Units	Adult	Children
Exposure duration	ED	Years	30	6
Exposure frequency	EF	Days/year	350	350
Averaging time	AT (ED×365)	Days	10,950	2190
Body weight	BW	kg	70.0	15.0
Ingestion rate	IR	L/day	2.0	1.0

Source: USEPA (2004, 2006)

**Table 2** Oral reference dose (RfD) for heavy metals

Metal	RfD (mg/kg/day)
Fe	0.007
Mn	0.014
Zn	0.3
Cd	0.0005
Cr	0.0003
Ni	0.02

Source: USEPA IRIS (2011)

### Hazard index

Since more than one toxicant is present, the interactions are considered. The toxic risks due to potentially hazardous substances present in the same media are assumed to be additive. The HQs may then be summed to arrive at the overall toxic risk, the hazard index (Kolluru et al. 1996; Paustenbach 2002; Zheng et al. 2010).

$$HI = \sum_{i=1}^n (HQ)_i \tag{3}$$

where HI is the hazard index for the overall toxic risk and n is the total number of metals under consideration. If  $HI < 1.0$ , the non-carcinogenic adverse effect due to this exposure pathway or chemical is assumed to be negligible.

## Results

### Heavy metal content

The summary of the heavy metal content is presented in Table 3.

The iron values ranged between 1.11 and 2.98 mg/l. All the values exceeded the acceptable limit set by SON (2015). One-way analysis of variance (ANOVA) showed that there was a significant difference; Station 1 was the source of the variation.

The manganese values ranged between 0.09 and 0.40 mg/l. Some of the values recorded in Station 1 from February to June and Station 2 in January, respectively, exceeded the acceptable limit. One-way analysis of variance (ANOVA) test showed that there was a significant difference; stations 1 and 2 were the sources of the variation.

The zinc values ranged between 0.55 and 1.33 mg/l. The values exceeded the acceptable limit set by SON (2015). One-way analysis of variance (ANOVA) test showed that there was a significant difference in all the stations.

The copper values ranged between 0.03 and 0.30 mg/l. All the values were within the acceptable limits. Station 1

**Table 3** Summary of heavy metals measured at Ossah River in Umuahia (with range in parenthesis)

Parameter (mg/l)	Station 1 $X \pm S.E$	Station 2 $X \pm S.E$	Station 3 $X \pm S.E$	<i>P</i> value	SON 2015*
Iron (Fe)	2.46 ± 0.16 <sup>a</sup> (1.84–2.98)	1.76 ± 0.21 <sup>b</sup> (1.32–2.70)	1.57 ± 0.26 <sup>b</sup> (1.11–2.84)	< 0.05	0.003
Manganese (Mn)	0.30 ± 0.04 <sup>a</sup> (0.12–0.40)	0.18 ± 0.04 <sup>a</sup> (0.11–0.38)	0.12 ± 0.01 <sup>b</sup> (0.09–0.14)	< 0.05	0.2
Zinc (Zn)	1.12 ± 0.06 <sup>a</sup> (0.92–1.33)	0.88 ± 0.05 <sup>b</sup> (0.73–1.05)	0.67 ± 0.04 <sup>c</sup> (0.55–0.80)	< 0.05	0.05
Copper (Cu)	0.22 ± 0.03 <sup>a</sup> (0.08–0.30)	0.10 ± 0.01 <sup>b</sup> (0.03–0.07)	0.09 ± 0.01 <sup>b</sup> (0.07–0.11)	< 0.05	3.0
Chromium (Cr)	0.09 ± 0.01 <sup>a</sup> (0.03–0.11)	0.05 ± 0.01 <sup>b</sup> (0.03–0.07)	0.03 ± 0.002 <sup>b</sup> (0.02–0.04)	< 0.05	0.02
Cadmium (Cd)	0.06 ± 0.01 <sup>a</sup> (0.04–0.08)	0.04 ± 0.05 <sup>a</sup> (0.03–0.06)	0.03 ± 0.01 <sup>b</sup> (0.02–0.05)	< 0.05	0.01
Nickel (Ni)	0.03 ± 0.01 <sup>a</sup> (0.02–0.04)	0.02 ± 0.003 <sup>a</sup> (0.01–0.03)	0.01 ± 0.002 <sup>b</sup> (0.01–0.02)	< 0.05	0.02
Lead (Pb)	0.11 ± 0.01 <sup>a</sup> (0.05–0.14)	0.05 ± 0.004 <sup>b</sup> (0.04–0.07)	0.03 ± 0.003 <sup>b</sup> (0.02–0.04)	< 0.05	1.0

a, b, c = means with different superscripts across the rows are significantly different at  $P < 0.05$

\*Nigerian Standard for Drinking Water Quality (NSDWQ) (SON 2015)

was the source of variation as one-way analysis of variance (ANOVA) showed that there was a significant difference in the stations.

The chromium values ranged between 0.02 and 0.11 mg/l. All the values in the three stations exceeded limits throughout the study. One-way analysis of variance (ANOVA) showed that there was a significant difference and Station 1 was the source of variation.

The cadmium values ranged between 0.02 and 0.08 mg/l. All the values exceeded acceptable limits. One-way analysis of variance (ANOVA) showed that there was a significant difference with stations 1 and 2 being the sources of the variation.

The nickel values ranged between 0.01 and 0.04 mg/l. Some of the values recorded in Station 1 and Station 2 from April to June 2018 exceeded the acceptable limits. One-way analysis of variance (ANOVA) test showed that there was a significant difference and stations 1 and 2 were the sources of the variation.

The lead values ranged between 0.02 and 0.08 mg/l. The values recorded were all within the acceptable limits. One-way analysis of variance (ANOVA) test showed that there

was a significant difference and Station 1 was the source of the variation.

## Health risk assessment

### Chronic daily intake

The chronic daily intake (CDI) of the assessed heavy metals is presented in Table 4. The CDI values of 0.068 mg/kg/day and 0.157 mg/kg/day for adult and children, respectively, were recorded for iron (Fe) in Station 1; in Station 2, 0.0482 mg/kg/day and 0.113 mg/kg/day were recorded, while in Station 3, 0.0430 mg/kg/day and 0.100 mg/kg/day were recorded, respectively. Manganese was only recorded in Station 1 where the limit was exceeded. The CDI values for adult and children were 0.008 mg/kg/day and 0.019 mg/kg/day, respectively. The CDI values of zinc (Zn) for adult and children in Station 1 were 0.031 mg/kg/day and 0.072 mg/kg/day, respectively, Station 2 (0.024 mg/kg/day and 0.056 mg/kg/day), respectively, and Station 3 (0.018 mg/kg/day and 0.042 mg/kg/day), respectively. The CDI values of chromium (Cr) for adult and children in Station 1 were

**Table 4** The chronic daily intakes of the heavy metals (mg/kg/day)

Metal	Station 1		Station 2		Station 3	
	Adult	Children	Adult	Children	Adult	Children
Iron (Fe)	0.068	0.157	0.048	0.113	0.043	0.100
Manganese (Mn)	0.008	0.019	–	–	–	–
Zinc (Zn)	0.031	0.072	0.024	0.056	0.018	0.042
Chromium(Cr)	0.002	0.006	0.001	0.003	0.001	0.001
Cadmium (Cd)	0.002	0.004	0.001	0.003	0.001	0.001
Nickel (Ni)	0.001	0.002	–	–	–	–

0.002 mg/kg/day and 0.006 mg/kg/day, respectively, Station 2 (0.001 mg/kg/day and 0.003 mg/kg/day), respectively, and Station 3 (0.001 mg/kg/day and 0.001 mg/kg/day), respectively. The CDI values of cadmium (Cd) for adult and children in Station 1 were 0.002 mg/kg/day and 0.004 mg/kg/day, respectively, Station 2 (0.001 mg/kg/day and 0.003 mg/kg/day), respectively, and Station 3 (0.001 mg/kg/day and 0.001 mg/kg/day), respectively. Nickel was also recorded only in Station 1 where it exceeded limit. The CDI values for adult and children were 0.001 mg/kg/day and 0.002 mg/kg/day, respectively.

### Hazard quotient (HQ)

The hazard quotient (HQ) of the assessed heavy metals is presented in Table 5. The HQ of Fe for adult and children is 9.71 and 22.4, respectively, in Station 1; 6.85 and 16.41 in Station 2; 6.14 and 14.28 in Station 3. The HQ for Fe for both adult and children was greater than 1 in all the stations. The HQ of Mn for adult and children is 0.57 and 1.36, respectively, in Station 1. The HQ for children was greater than 1. The HQ of Zn for adult and children is 0.10 and 0.24, respectively, in Station 1; 0.08 and 0.18 in Station 2; 0.06 and 0.14 in Station 3. The HQ of Zn for adult and children in Stations 1, 2 and 3 was less than 1. The HQ of Cr for adult and children is 0.67 and 20, respectively, in Station 1; 3.33 and 10 in Station 2; 3.33 and 3.33 in Station 3. The HQ of Cr for children in Station 1, adults and children in stations 2 and 3 were greater than 1. The HQ of Cd for adult and children is 4 and 8, respectively, in stations 1, 2 and 6 in Station 2, 2 and 2 in Station 3. The HQ of Cd for adult and children in all the stations was greater than 1. The HQ of Ni for adult and children is 0.05 and 0.1 only in station 1. The HQ for both adult and children was less than 1.

### Hazard index

Hazard indices (HI) recorded for adults and children in the 3 stations were far greater than threshold value (1). Hence, the non-carcinogenic adverse effect cannot be overlooked.

## Discussion

### Heavy metal content

#### Heavy metal content

All of the values of iron exceeded the acceptable limits sets and could be as a result of geogenic influence increased by anthropogenic activities especially in stations 1 and 2. The values recorded in this study were lower compared to values recorded in related studies. Ekere et al. (2014) recorded values of between 0.75 and 15.01 mg/l in some drinking water sources in South-East Nigeria, while Anyanwu and Onyele (2018) recorded values of between 1.12 and 5.10 mg/l in a rural spring also in South-East Nigeria. Iron (Fe) is an indispensable metal for humans and most living organisms. Proteins and many enzymes, including haemoglobin, and myoglobin have iron as a major component. The higher concentration of iron in freshwater environment than other metals in Nigeria is as a result of its high occurrence on earth (Adefemi et al. 2004; Aiyesanmi 2006). Conditions like anaemia and fatigue could result from Fe deficiency, which are usually common among children (under 5 years), pregnant women and immunocompromised individuals, predisposing them to numerous disease conditions (Garvin 2015). High concentration of iron could result in neurological effects (Zheng et al. 2003), while iron-mediated oxidative damage of the mitochondrial genome resulting in progressive dysfunction could arise from long-term exposure to iron toxicity (De Freitas and Meneghini 2001).

Some of the recorded values of manganese were higher than the acceptable limits especially in Stations 1 and 2 and could be as a result of the combined effects of all the anthropogenic activities going on around Station 1 (Clark 1994) and effect of the effluent discharged upstream of Station 2. The values recorded in this study were within the range of 0.06–0.51 mg/l recorded by Anyanwu and Onyele (2018) in a rural spring in South-East, Nigeria. Manganese is an essential micronutrient in all living organisms because they act as a co-factor for many enzyme activities (Suresh

**Table 5** Hazard quotients and total hazard index of the heavy metals

Metal	Station 1		Station 2		Station 3	
	Adult	Children	Adult	Children	Adult	Children
Iron (Fe)	9.71	22.4	6.85	16.14	6.14	14.28
Manganese (Mn)	0.57	1.36	–	–	–	–
Zinc (Zn)	0.10	0.24	0.08	0.18	0.06	0.14
Chromium (Cr)	0.67	20	3.33	10	3.33	3.33
Cadmium (Cd)	4	8	2	6	2	2
Nickel (Ni)	0.05	0.1	–	–	–	–
HI	21.1	52.1	12.26	32.32	11.53	19.5



et al. 1999). Manganese also has a considerable biological significance with low toxicity. In most countries, having high concentrations of manganese in drinking water is quite common. (Ljung and Vahter 2007). Manganism is a disease condition that could arise as a result of exposure to very high amount of manganese (Bradi 2005; Dieter et al. 2005). Bouchard et al. (2007) associated levels of manganese in drinking water with cognitive behavioural problems in children. High levels of manganese interfere with the absorption of dietary iron and could result in iron-deficiency anaemia due to long-term exposure to manganese in high concentrations. Increased manganese intake also impairs the activity of copper metallo-enzymes. Symptoms akin to those of Parkinson's disease (tremors, stiff muscles) could manifest from manganese toxicity, while hypertension among patients older than 40 can also result from excessive intake (Blau-rock-Busch n.d.).

All values of Zn recorded exceeded acceptable limit especially in Stations 1 and 2. Geological influence as well as anthropogenic impacts could be responsible. Anyanwu and Onyele (2018) recorded relatively higher values (0.21–0.90 mg/l) in a rural spring in South-East, Nigeria. Zn is also an essential element in the lives of animal and human beings. It is available in almost all food and potable water in the form of salts or organic complexes (WHO 2017). Zinc poisoning is known to affect bone growth as well as the development and functioning of reproductive organs though its cases are rare (Bytyçi et al. 2018). Diarrhoea, bloody urine, liver failure, kidney failure and anaemia are some of the clinical symptoms associated with Zn toxicity (Duruibe et al. 2007).

Copper was not considered a problem in this study because all the values of copper were within acceptable limit. In Stations 1 and 2, relatively higher values were recorded which may be due to anthropogenic activities. Lower values of 0.02–0.15 mg/l were recorded by Anyanwu and Onyele (2018) in a rural spring in South-East Nigeria, while Ekere et al. (2014) recorded higher values of 0.21–2.65 mg/l in some drinking water sources also in South-East Nigeria.

The chromium values recorded exceeded acceptable limit. Geological influence as well as anthropogenic activities could be responsible; especially in Stations 1 and 2. These values were lower than 0.01–0.24 mg/l recorded by Anyanwu and Onyele (2018) in a rural spring in South-East, Nigeria, and 0.01–0.65 mg/l recorded by Ekere et al. (2014) in some drinking water sources also in South-East Nigeria. Cr is also an essential micronutrient for animals and plants. It is an element considered to be of relative biological and pollution importance (Rajappa et al. 2010). Chromium is essential in human nutrition; when found within the recommended limit in drinking water, it helps in the maintenance of the normal glucose metabolism. At concentrations above the recommended level, chromium can cause dermatitis and

ulceration of the skin (Lajçi et al. 2017), while kidney, liver, circulatory and nerve tissue damages could result from long-term exposure (Strachan 2010).

All the cadmium values exceeded acceptable limit especially in Stations 1 and 2 and could be due to anthropogenic activities. These values were lower than 0.01–0.43 mg/l recorded by Anyanwu and Onyele (2018) in a rural spring in South-East, Nigeria, and 0.00–0.25 mg/l recorded by Ekere et al. (2014) in some drinking water sources also in South-East Nigeria. It is a non-essential element capable of causing toxicity (Bytyçi et al. 2018). Small quantities of cadmium can cause adverse changes in the arteries of human kidney. According to Rajappa et al. (2010), Cd replaces Zn biochemically and causes hypertension as well as kidney damage. It also interferes with enzymes and causes a painful disease called Itai-itai. Acute Cd poisoning in humans can be very serious, resulting in hypertension, kidney damage, potential prostate cancer, etc. (Durmishi et al. 2016).

Some of the Ni values recorded in Stations 1 and 2 exceeded the acceptable limits. These values were lower than 0.005–0.25 mg/l recorded by Anyanwu and Onyele (2018) in a rural spring in South-East, Nigeria. Ni is an important metal for several animal species, microorganisms and plants; therefore, either deficiency or toxicity symptoms could result from too little or too much, respectively (Bytyçi et al. 2018). Anthropogenic release and geogenic varying levels in some areas could both contribute to nickel toxicity to living organisms, though it is widespread and vital for the function of many organisms (Diagomanol et al. 2004). The toxicity affects the respiratory tract and immune system. A major source of Ni exposure to the general population is primarily through the oral intake—water and food (Bytyçi et al. 2018).

Lead was also not considered as a problem in this study because all the values were within acceptable limit, though Station 1 had higher values. These values were lower than 0.01–0.72 mg/l recorded by Anyanwu and Onyele (2018) in a rural spring in South-East, Nigeria, and 0.38–3.04 mg/l recorded by Ekere et al. (2014) in some drinking water sources also in South-East Nigeria.

## Health impact assessment

### Chronic daily intake

The chronic daily intake (CDI) values of iron for adult and children were above oral reference dose (RfD) (0.007 mg/kg/day). The high iron CDI values could be as a result of high iron content of the river exacerbated by low pH. Lenntech (n.d.) reported that the solubility of some iron compounds in water is increased at lower pH. Ekere et al. (2014), Maigari et al. (2016) and Onyele and Anyanwu (2018) equally recorded high iron CDI values. Thus, iron is a potential

health risk to those exposed to drinking water from the river. The CDI value of manganese for adult was below oral reference dose (RfD) of 0.014 mg/kg/day, while that of children exceeded the RfD. Maigari et al. (2016) recorded CDI values of the same range with this study. Manganese was not considered a potential risk to adults exposed to the water of Ossah but not the children. CDI values of zinc for adult and children were below oral reference dose (RfD) (0.3 mg/kg/day); as a result, zinc was not considered a potential risk to those exposed to the water of Ossah River through ingestion. Maigari et al. (2016) recorded lower CDI values for Zn. CDI values of chromium for adult and children were above oral reference dose (RfD) (0.0003 mg/kg/day). Ayantobo et al. (2014), Ekere et al. (2014) and Onyele and Anyanwu (2018) equally recorded high chromium CDI values. The high chromium CDI values could be as a result of natural and human influences. Chromium is a potential health risk to those exposed to drinking water from the river. CDI values of cadmium for adult and children were above oral reference dose (RfD) (0.0005 mg/kg/day). Ayantobo et al. (2014), Ekere et al. (2014), Maigari et al. (2016) and Onyele and Anyanwu (2018) recorded similar higher cadmium CDI values. The high cadmium CDI values could be as a result of natural and human influences. Thus, cadmium is a potential health risk to those exposed to drinking water from the river. CDI values of nickel for adult and children as recorded only in Station 1 were below oral reference dose (RfD) of 0.02 mg/kg/day; as a result, it is not a potential health risk to those exposed to the water through ingestion in Station 1. Maigari et al. (2016) recorded low CDI values of 0.0196 mg/kg/day and 0.00308 mg/kg/day for adults and children in water from Gombe Abba River.

### Hazard quotient (HQ) and hazard index (HI)

The hazard quotient (HQ) for the metals in all the stations was greater than 1. In all the stations, iron exceeded limit (1), while manganese exceeded limit in only Station 1 and for children. Zinc was lower than the limit in all the stations for both adults and children. Cadmium exceeded limit in all the stations for both adults and children, while chromium also exceeded limit in all the stations for both adults and children except for adults in Station 1. Some of HQ values were especially high for children, thereby making them more vulnerable. Ekere et al. (2014) and Onyele and Anyanwu (2018) equally recorded HQ > 1 for some of the metals considered in this study. HQ values observed in this study were contributed by the high CDI values recorded for some of the metals evaluated. These metals could pose a long-term health risk to the water users in all the stations concerned. It is in line with the findings of Ayantobo et al. (2014), Ekere et al. (2014), Maigari et al. (2016) and Onyele and Anyanwu (2018). The long-term health risk observed was high, and

the non-carcinogenic adverse effect cannot be overlooked or considered insignificant.

### Conclusion

Some of the heavy metals evaluated exceeded limits and necessitated health risk assessment. Health risk assessment for all the stations did not implicate any single heavy metal, but their cumulative impact manifested in the hazard index (HI). Hazard index (HI) for all the stations highly exceeded threshold value of 1. This has far reaching consequences for both adults and children exposed to the water through ingestion. The heavy metal contamination observed was generally geogenic which was increased as a result of anthropogenic activities.

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### Compliance with ethical standards

**Conflict of interest** The authors hereby state that this research work and manuscript production complied with ethical standards, and none of the authors has any potential conflict of interest. We further declare that this research was not funded by any agency.

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