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Drinking water status and Health Risk Assessment of a South-Eastern Nigeria River

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ABSTRACT

Purpose: Drinking water is one of the ecosystem services derived from lotic systems especially in developing countries. However, drinking from water sources of doubtful quality portends serious health risks. The heavy metal concentrations of a rural Southeastern Nigeria river were evaluated between November 2023 and October 2024 to determine its drinking water status and potential health risks.

Methods: Chemical analysis, Water Pollution Index (WPI), Risk Quotient (RQ) and non-carcinogenic health risk assessment were used. Eight heavy metals were evaluated, using standard methods and compared with Nigerian Standard for Drinking Water Quality.

Results: The concentrations were iron (0.62 – 1.65 mg/L), manganese (0.24 – 1.10 mg/L), copper (0.18 – 0.93 mg/L), zinc (0.39 – 1.23 mg/L), chromium (Cr(VI)) (0.09 - 0.56 mg/L), lead (0.05 - 0.37 mg/L), cadmium (0.01 - 0.28 mg/L), and nickel (0.02 - 0.19 mg/L). All exceeded their limits except copper and zinc. WPI values were > 1, ranging from 8.22 (station 2) to 9.58 (station 3); indicating serious pollution while risk quotient (RQ >1) confirmed that iron, manganese, chromium (VI), lead, cadmium, and nickel were of health interest. The hazard indices (HI) were > 1, with adults ranging from 7.91 (station 2) to 9.14 (station 3) and children from 10.86 (station 2) to 12.66 (station 3). Anthropogenic activities within the watershed and season influenced the metals. Chromium, lead, nickel and cadmium contributed to the observed adverse health risks, which was more on the children.

Conclusion: The Anya River water is not potable but can be used for other domestic purposes like washing, cleaning and irrigation.

Keywords: Heavy metal; potable; drinking water; indices; season, river.

1. Introduction

In the world, rivers are the most important freshwater resources. Nonetheless, the quality, quantity, and accessibility of water resources are under severe and varied pressure due to growing human development, industrialization, and population increase (Proshad et al., 2021; Bănăduc et al., 2024). Constant monitoring of river water is necessary to determine the pollution status and identify the factors responsible for the pollution. The nature of pollutants introduced into the aquatic ecosystem is largely dependent of the diversity and intensity of anthropogenic activities taking place within the watershed (Akhtar et al,. 2021).

Heavy metal contamination of the aquatic environment has spread throughout the globe and has become a worldwide problem (Ahamad et al., 2024). Heavy metals (HMs) are elements with high atomic weights and a density five times that of water (Paithankar et al., 2021). Because of its environmental toxicity, abundance, permanence, and toxicological impacts on human health, heavy metals (HM) in aquatic environments have been attracting attention from all over the world (Cui et al., 2021; Mahabeer and Tekere, 2021; Hao et al., 2022; Nijeje et al., 2023). Both natural processes (like rock weathering and volcanic eruptions) and man-made ones (like industrial operations, farming, fuel burning, household waste, and discharge runoffs) are the sources of heavy metal build-up in surface water (Hoang et al., 2021; Islam et al., 2022; Odewumi and Omoniwa, 2024). These activities raise the concentrations of environmental heavy metals (HMs) as a result of large amounts being released into rivers and lakes worldwide annually (Cui et al., 2021; Paithankar et al., 2021; Norvivor et al., 2024).

For a variety of uses, water quality indices have been developed to facilitate the simple interpretation and reporting of water quality. Hossain and Patra (2020) developed the Water Pollution Index (WPI), which has been effectively utilized by researchers to assess the quality of water for various uses (Abualhaija, 2023; Agbasi and Egbueri, 2023; Akther et al., 2023; Adetunji et al., 2025). On the other hand, risk quotient (RQ) was introduced by Wan Mohtar et al. (2019) to facilitate quick environmental risk assessment especially where very strict standard is required.

Studies on the health effects of drinking from waterbodies contaminated with heavy metals have been conducted all over the world (Ahmad et al., 2021; Zhang et al., 2021; Odo et al., 2022; Zhao et al., 2022; Badeenezhad et al., 2023; Adetunji et al., 2025). Chronic Daily Intake (CDI), hazard quotient (HQ), and hazard index (HI) are the parameters used to evaluate the non-cancer health risks associated with heavy metal exposure in humans (Anyanwu et al., 2020; Ugwu et al., 2022; Badeenezhad et al., 2023; Ogarekpe et al., 2023). Therefore, the potential health risk of the heavy metal contents of the Anya River was assessed using these indices.

Nnono Oboro is an agrarian community with high dependence on Anya River. The usefulness of the river is more obvious during the dry season when it is utilized for drinking, irrigation, and other domestic uses. Hence, the purpose of this study is to assess the suitability of Anya River for drinking based on the heavy metal content and potential health risks.

2. Materials and Methods

2.1. Study area and sampling stations

This study was conducted at Anya River located in Nnono Oboro, Ikwuano Local Government Area, Abia state, Southeast Nigeria. It lies within Latitude 5°26'17.5''-5°25'43.9''N and Longitude 7°31'52.2''E- 7° 31'45.7''E (Figure 1). The climate is dominated by two (2) distinct seasons - rainy season (May to October) and dry season (November to April) with a double maxima rainfall peaks in July and September and a short dry season of about two weeks between the peaks locally known as the "August break".

Station 1 (Iyi-Umuohi) is upstream and lies within Latitude 5°26'17.5''N and Longitude 7°31'52.2''E. The station is located by a bridge, open and relatively deeper than stations 2 and 3. The station was dedicated to extraction of water for drinking and food processing (cassava and bread fruit).

Station 2 (Iyi-Umuogwara) is located about 656.27 meters downstream of station 1. It lies within Latitude 5°25'56.7''N and Longitude 7°31'47.8''E. Human activities observed during the study include extraction of water for drinking, food processing and washing of clothes. There is a rice farm close to the station. Stormwater from the community discharges into the river after this station during and after rainfall events.

Station 3 (Iyi-Umumba) is located about 399.90 meters downstream to station 2. It lies within Latitude 5°25'43.9''N and Longitude 7°31'45.7''E. Human activities observed during the study include extraction of water for drinking, washing of clothes, food processing, swimming and bathing.

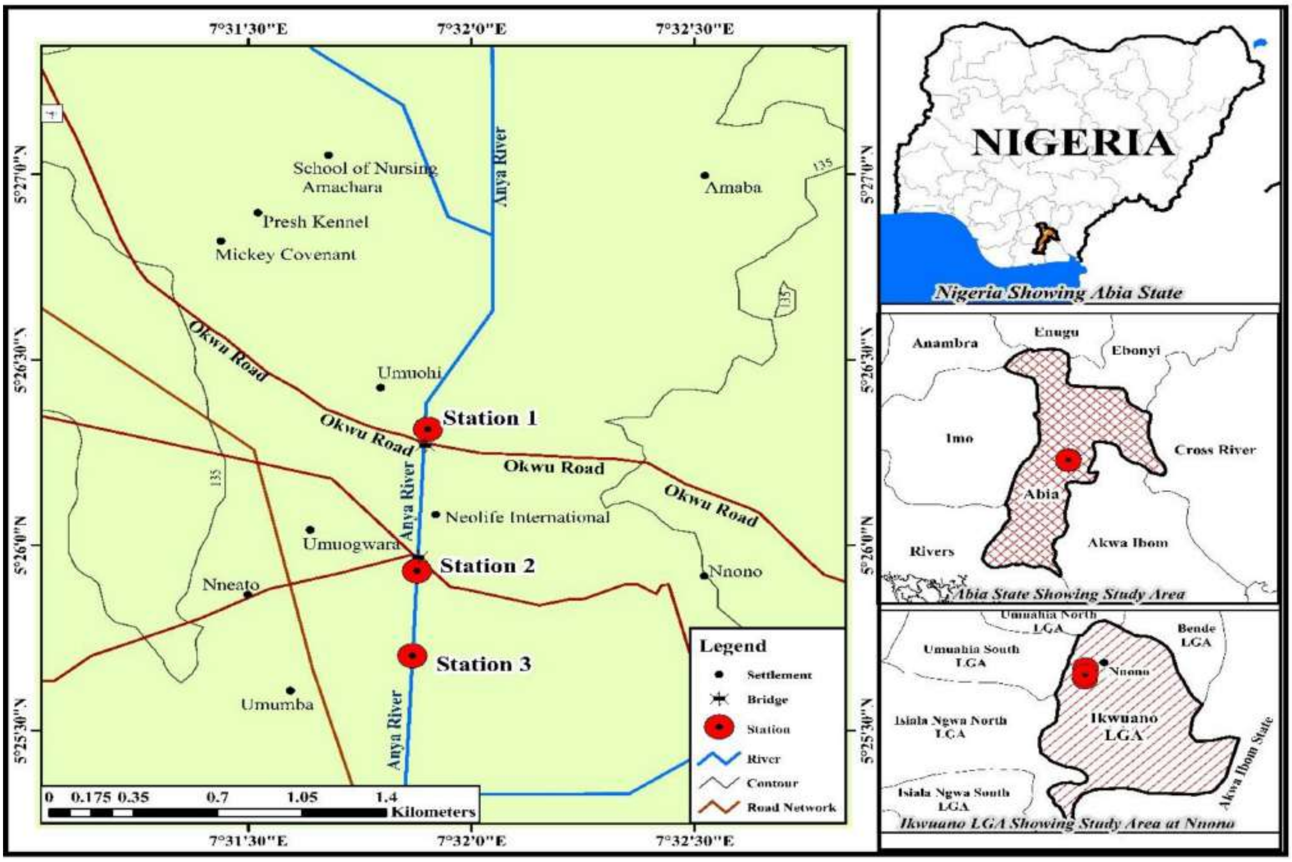
2.2. Samples collection and analyses

Water samples were collected from Anya River at Nnono-Oboro once every month between November 2023 and October 2024. One litre water sampler was used and transferred into clean 250 ml plastic bottles. The pH of the samples was reduced by adding drops of nitric acid (HNO_3) immediately after collection according to Sharma and Tyagi (2013). Eight (8) heavy metals (iron, manganese, copper, chromium as Cr(VI), lead, cadmium and nickel) were determined directly with a UNICAM Solaar 969 Atomic Absorption Spectrometer (AAS) being operated with acetylene-air flame. Analytical quality control and assurance measures involved the daily preparation of the working solutions for the analysis of different metals by making a stock solution with the mixture of 65% (v/v) HNO_3, 30% (v/v) H_2O_2 and H_2O (v/v/v = 1:1:3) ratios. The analysis of each sample was done once while the analytical blanks were ran the same way as the samples, and the values recorded during the analysis were deducted from the values of each sample in order to get the real values.

2.3. Statistical Analysis

The heavy metal results were analyzed to get the mean, standard error of the mean, minimum and maximum for each metal using with Microsoft Excel. Normality tests were carried

Figure 1.
Map of Anya River at Nnono- Oboro, Abia State, Nigeria showing the sampling Stations.



out with Shapiro-Wilk test. One-way analysis of variance (ANOVA) was used to test for significant differences among the stations and months independently while Turkey pairwise was used locate the source of the variations. The normality tests, one-way ANOVA and post hoc (Turkey pairwise) were carried with PAST Statistical (version 4.03) at significant level of $p < 0.05$ (Hammer et al., 2001).

3. Water Quality Assessment

3.1. Water pollution index (WPI)

Water pollution index was used to evaluate the quality of the river based on the heavy metal content. The WPI was developed by Hossain and Patra (2020). The first step was to determine the pollution load of ith parameter using equation 1:

$$PLi = 1 + \left(\frac{C_i - S_i}{S_i}\right) \quad \text{(Equation 1)}$$

where, C_i is the analyzed value of ith parameter, S_i is the highest acceptable limit for the parameter. The standard used was Nigerian standard for drinking water quality (SON, 2015). Secondly, the WPI of the water samples with *n* number of variables (parameters) was determined by adding up all the pollution loads and dividing with *n* (equation 2). However, parameters with values of 0 must not be considered in the total 'n' of any sample.

$$WPI = \frac{1}{n} + \Sigma_{i=1}^{n} PL_i \quad \text{(Equation 2)}$$

3.2. Risk Quotient (RQ)

Risk quotient (RQ) is the ratio of measured environmental level to the acceptable limit. The approach facilitates quick environmental risk assessment especially where very strict standard is required (Wan Mohtar et al., 2019). Hence, RQ was used to determine the heavy metals that were used for health risk assessment. The Risk Quotient (RQ) for single metals was calculated using equation 3 by Ariff et al. (2023).

$$RQ = \frac{MEC\ (Analytical\ value)}{PNEC\ (Environmental\ Standards)} \quad \text{(Equation 3)}$$

where, MEC is the analytical value of the measured environmental parameter and PNEC is the environmental standard. This study adopted Nigerian standard for drinking water quality (SON, 2015) as the PNEC values according to Karki et al. (2024). RQ value (<1) is an indication of no potential ecological risk, while RQ value (>1) indicates a potential ecological risk, which should not be neglected (Backhaus & Faust, 2012). Higher values are indications of greater potential risks (Gu, 2021).

3.3. Health Risk Assessment

The heavy metals assessed for potential human health risks through oral ingestion were Fe, Mn, Cr, Pb, Cd, and Ni. They exceeded limits set by the Nigerian Standard for Drinking Water Quality (SON, 2015) and had RQs greater than 1.

3.4. Chronic Daily Intake (CDI)

The chronic daily intake (CDI) of the metals was calculated for oral ingestion exposure using equation 4 (Moldovan et al., 2020):

$$CDI = \frac{Cw\ x\ IR\ x\ EF\ x\ ED}{Bw\ x\ AT} \quad \text{(Equation 4)}$$

Where, CDI in mg/kg/day is the daily amount of contaminant, a consumer can take in through ingestion; Cw is the mean analytical value of the metal (mg/L). IR is the minimal daily water consumption by adults and children, EF represents the frequency of the exposure, ED represents duration of the exposure, BW represents the mean body weight, and AT represents the mean exposure time.

Presented in Table I are parameters and assigned values for CDI calculation.

Table I

Parameters and assigned values for Health Risk Assessment

Parameter	Symbol	Units	Adult	Children
Exposure Duration	ED	Years	70	10
Exposure Frequency	EF	Days/ year	365	365
Averaging time	AT (ED x 365)	Days	25550	3650
Body Weight	BW	Kg	70.0	25.0
Ingestion rate	IR	L/day	2.0	1.0

Source: (USEPA, 1999; Moldovan et al., 2020).

3.5. Hazard Quotient

Hazard Quotient (HQ) is an estimate of the toxicity potential of a contaminant as a result of oral exposure. The Hazard Quotient (HQ) for non-carcinogenic risk for oral route was determined by equation 5 from USEPA (2004):

$$HQ = \frac{chronic\ daily\ intake\ (CDI)}{Oral\ Reference\ Dose\ (RfD)} \quad \text{(Equation 5)}$$

Where, CDI in mg/kg/day is the daily dose of heavy metals to which a consumer might be exposed and RfD represents oral reference dose (mg/kg/day) of each of the metals evaluated. It is the daily amount that an individual can bear for a long time without resulting in any negative effect. If, HQ > 1, it indicates adverse non-carcinogenic effects that cannot be neglected, while HQ < 1 indicates an acceptable level.

3.6. Hazard Index (HI)

Hazard index (HI) is the potential cumulative effect of more than one heavy metal through ingestion pathway and can be estimated using equation 6.

$$HI = \Sigma_{i=1}^{n} HQ \quad \text{(Equation 6)}$$

Where, HI is an estimate of the overall toxicity potentials of the contaminants while *n* is the number of contaminants used in the assessment. If HI for non-carcinogenic adverse effect due to oral exposure is lower than one (HI < 1.0), then no chronic risks are expected to occur but if HI is greater than one (HI > 1.0), possible chronic risk arising from the water ingestion exposure could occur (Moldovan et al., 2020).

4. Results

4.1. Spatial and temporal variations of heavy metals

The summary of the heavy metal concentrations is presented in Table II. Iron (Fe) values ranged from 0.62 mg/L to 1.65 mg/L. The values (100%) exceeded the acceptable limit (0.3 mg/L) set by SON (2015) for drinking water in the stations and months. The lowest value was recorded in Station 1 (July 2024) while the highest was Station 3 (January 2024) (Fig. 2a). Spatial variation was not significant ($p > 0.05$). However, November 2023 was significantly higher ($p < 0.05$) than August and September 2024 while January, February and April 2024 were significantly higher ($p < 0.05$) than June to October 2024.

Manganese (Mn) values ranged from 0.24 mg/L to 1.10 mg/L. The values (100%) exceeded the acceptable limit (0.2 mg/L) set by SON (2015) for drinking water in the stations and months. The lowest value was recorded in Station 1 (July 2024) while the highest was Station 3 (April 2024) (Fig. 2b). Spatial variation was not significant ($p > 0.05$). However, April 2024 was significantly higher ($p < 0.05$) than November and December 2023 and May to October 2024 while March 2024 was significantly higher ($p < 0.05$) than August 2024.

The values of chromium (Cr(VI)) ranged from 0.09 mg/L to 0.56 mg/L. All the values (100%) exceeded the acceptable limit (0.05 mg/L) set by SON (2015) for drinking water in the stations and months. The lowest value was recorded in Station 1 (June 2024) while the highest was Station 3 (January 2024) (Fig. 2c). Spatial variation was not significant ($p > 0.05$). However, January 2024 was significantly higher ($p < 0.05$) than November 2023, June to September 2024 while April 2024 was significantly higher ($p < 0.05$) than June and August 2024.

Cadmium (Cd) values ranged from 0.01 mg/L to 0.28 mg/L. The values (100%) exceeded the acceptable limit (0.003 mg/L) set by SON (2015) for drinking water in the stations and months. The lowest value was recorded in Station 2 (September 2024) while the highest was Station 1 (April 2024) (Fig. 2d). Spatial variation was not significant ($p > 0.05$). However, April 2024 was significantly higher ($p < 0.05$) than November and December 2023, June to September 2024 while May 2024 was significantly higher ($p < 0.05$) than September 2024.

Zinc (Zn) values ranged from 0.39 mg/L to 1.23 mg/L. The values (100%) were within the acceptable limit (3 mg/L) set by SON (2015) for drinking water in the stations and months. The lowest value was recorded in Station 1 (July 2024) while the highest was Station 1 (March 2024) (Fig. 2e). Spatial variation was not significant ($p > 0.05$). However, April 2024 was significantly higher ($p < 0.05$) than November and December 2023, June to October 2024 while March 2024 was significantly higher ($p < 0.05$) than July 2024.

Nickel (Ni) values ranged from 0.02 mg/L to 0.19 mg/L. The values (100%) exceeded the acceptable limit (0.02 mg/L) set by SON (2015) for drinking water in Station 3, 91.67% in Stations 2 (except in August 2024) and 83.33% in Station 1 (except in June and July 2024). The lowest values were recorded in Stations 1 (June and July 2024) and 2 (August 2024) while the highest was Station 1 (March 2024) (Fig. 2f). Spatial variation was not significant ($p > 0.05$). However, April 2024 was significantly higher ($p < 0.05$) than June to August 2024.

Table II

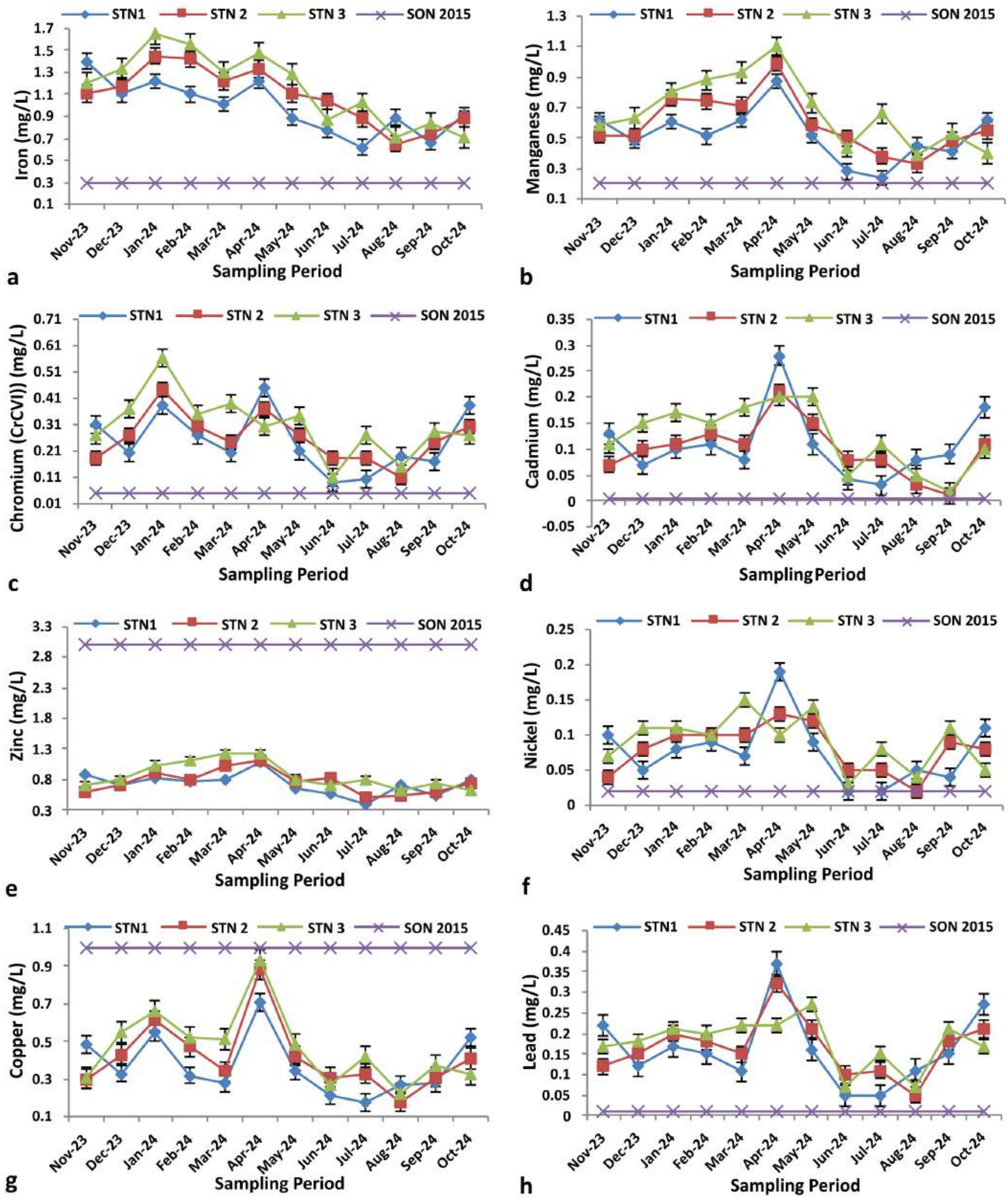
The Summary of the Heavy Metal Values of Anya River at Nnono –Oboro, Abia State, Nigeria

Metals (mg/L)	STN1 Mean±SEM	STN 2 Mean±SEM	STN 3 Mean±SEM	Station P-value	Month P-value	SON 2015
Iron	0.98±0.07 (0.62-1.40)	1.08±0.07 (0.65-1.45)	1.16±0.09 (0.71-1.65)	F= 1.27 P= 0.30	F= 7.44 P= 0.00	0.3
Manganese	0.52±0.05 (0.24-0.87)	0.59±0.05 (0.33-0.99)	0.67±0.06 (0.39-1.10)	F= 1.89 P= 0.17	F= 6.05 P= 0.00	0.2
Chromium (Cr(VI))	0.25±0.03 (0.09-0.45)	0.26±0.03 (0.11-0.44)	0.31±0.03 (0.11-0.56)	F= 1.04 P= 0.37	F= 5.25 P= 0.00	0.05
Cadmium	0.11±0.02 (0.03-0.28)	0.10±0.02 (0.01-0.21)	0.12±0.02 (0.02-0.20)	F= 0.51 P= 0.60	F= 5.60 P= 0.00	0.003
Zinc	0.73±0.05 (0.39-1.08)	0.76±0.05 (0.51-1.11)	0.87±0.06 (0.64-1.23)	F= 1.78 P= 0.19	F= 4.96 P= 0.00	3
Nickel	0.08±0.01 (0.02-0.19)	0.08±0.01 (0.02-0.13)	0.09±0.01 (0.03-0.15)	F= 0.45 P= 0.64	F= 3.67 P= 0.00	0.02
Copper	0.37±0.05 (0.18-0.71)	0.42±0.05 (0.18-0.88)	0.46±0.06 (0.22-0.93)	F= 0.79 P=0.46	F= 9.97 P= 0.00	1
Lead	0.16±0.03 (0.05-0.37)	0.17±0.02 (0.05-0.32)	0.18±0.02 (0.07-0.27)	F= 0.18 P=0.83	F= 6.21 P= 0.00	0.01
WPI	8.52	8.22	9.58			

SEM= Standard Error of Mean; WPI = Water Pollution Index; SON (2015) = Nigerian standard for drinking water quality

Figure 2.

Spatial and temporal variations of the metals: (a) iron, (b) manganese, (c) chromium (Cr(VI)), (d) cadmium, (e) zinc, (f) nickel, (g) copper and (h) lead.



Copper (Cu) values ranged from 0.18 mg/L to 0.93 mg/L. The values (100%) were within the acceptable limit (1.0 mg/L) set by SON (2015) for drinking water in the stations and months. The lowest values were recorded in Stations 1 (July 2024) and 2 (August 2024) while the highest was Station 3 (April 2024) (Fig. 2g). Spatial variation was not significant ($p > 0.05$). However, April 2024 was significantly higher ($p < 0.05$) than November and December 2023, February and March 2024, May to October 2024 while January 2024 was significantly higher ($p < 0.05$) than June to September 2024.

Lead (Pb) values ranged from 0.05 mg/L to 0.37 mg/L. The values (100%) exceeded the acceptable limit (0.01 mg/L) set by SON (2015) for drinking water in the stations and months. The lowest values were recorded in Stations 1 (June and July 2024) and 2 (August 2024) while the highest was Station 1 (April 2024) (Fig. 2h). Spatial variation was not significant ($p > 0.05$). However, April 2024 was significantly higher ($p < 0.05$) than November and December 2023, March 2024, June to August 2024 while May and October 2024 were significantly higher ($p < 0.05$) than June and August 2024.

4.1.1. Water Pollution Index (WPI)

The water pollution index (WPI) for drinking water ranged between 8.22 and 9.58. The WPI benchmark for good quality water is <0.75 while values >1 indicate serious pollution. All the WPI values were >1; indicating serious heavy metal pollution. The lowest value was recorded in Station 2 while the highest was in Stations 3.

4.1.2. Risk Quotient (RQ)

The RQ values were greater than 1 except for zinc and copper (Table III). The RQ threshold value is 1. The RQ values (<1) recorded for zinc and copper indicated that there were no environmental risks associated with the metals. However, all RQ values (>1) indicated some level of environmental risks depending on the magnitude of the RQ. High RQ values were recorded for chromium, lead and cadmium; an indication of the level of their contribution to the environmental pollution and risk in the river.

Table III

The Risk Quotient values for Heavy Metals of Anya River at Nnono–Oboro, Abia State, Nigeria

Metal	STN1	STN 2	STN 3	RQ Status
Iron	3.27	3.60	3.87	>1
Manganese	2.60	2.95	3.35	>1
Chromium (Cr(VI))	5.00	5.20	6.20	>1
Cadmium	36.67	33.33	40.00	>1
Zinc	0.24	0.25	0.29	<1
Nickel	4.00	4.00	4.50	>1
Copper	0.37	0.42	0.46	<1
Lead	16.00	16.00	18.00	>1

4.2. Health Risk Assessment

4.2.1. Chronic Daily Intake (CDI)

The oral chronic daily intake (CDI) values for the heavy metals (Fe, Mn, Cr (Cr(VI)), Pb, Cd, and Ni) that exceeded limits are presented in Table IV with their respective oral reference doses (RfD). The health risk assessment showed that CDI values varied among the metals. Iron (Fe) and manganese (Mn) recorded CDI values that were lower than their respective oral reference doses. The other metals (Cr (Cr(VI)), Cd, Ni and Pb) recorded CDI values that were greater than their respective oral reference doses. All the CDI values increased spatially as observed in Fe and Mn except for Cd in station 2 (children) and Ni in stations 1 and 2 (adult and children). However, all the children CDI values were higher than that of adults.

Table IV

The Chronic Daily Intakes and Reference Doses of the Heavy Metals (mg/kg/day)

Metal	Station 1		Station 2		Station 3		Oral
	Adult	Children	Adult	Children	Adult	Children	RfD
Fe	0.028	0.039	0.031	0.043	0.033	0.046	0.7
Mn	0.015	0.021	0.017	0.024	0.019	0.027	0.14
Cr (Cr(VI))	0.0071	0.01	0.0074	0.01	0.0089	0.012	0.003
Cd	0.0031	0.0044	0.0029	0.004	0.0034	0.0048	0.001
Ni	0.0023	0.0032	0.0023	0.0032	0.0026	0.0036	0.002
Pb	0.0046	0.0064	0.0049	0.0068	0.0051	0.0072	0.004

4.2.2. Hazard Quotients (HQs)

The hazard quotients (HQs) for oral exposure are presented in Table V. Iron (Fe) and manganese (Mn) had HQ values that were lower than threshold value (1). The HQ values for the other metals (Cr (Cr(VI)), Cd, Ni and Pb) exceeded the threshold value (1). The values generally increased from stations 1 to 3, though stations 1 and 2 had the same values for Fe and Ni. Higher values were recorded among the children as observed in CDI (Fig. 3).

Table V

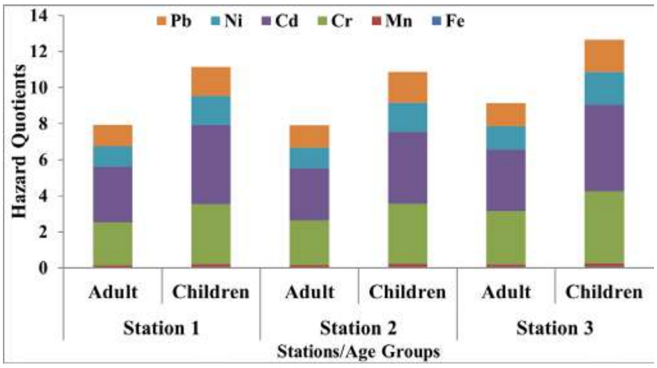
Hazard Quotients and Hazard Index of the Heavy Metals

Metal	Station 1		Station 2		Station 3	
	Adult	Children	Adult	Children	Adult	Children
Fe	0.04	0.06	0.04	0.06	0.05	0.07
Mn	0.11	0.15	0.12	0.17	0.14	0.19
Cr (Cr(VI))	2.37	3.33	2.47	3.33	2.97	4.00
Cd	3.10	4.40	2.90	4.00	3.40	4.80
Ni	1.15	1.60	1.15	1.60	1.30	1.80
Pb	1.15	1.60	1.23	1.70	1.28	1.80
HI(ΣHQ)	**7.92**	**11.14**	**7.91**	**10.86**	**9.14**	**12.66**

Hazard Quotient and Hazard Index Threshold value = 1

Figure 3

Relative contributions of the metals' Hazard Quotients to Hazard Index among the different age groups.4



4.2.3. Hazard Index

The hazard indices (HIs) values for oral exposure were also presented in Table V. The values ranged from 7.91 to 9.14 (adult) and 10.86 to 12.66 (children). The HI values exceeded the threshold value (1) in all the stations and among adult and children. Spatially, the values for station 2 (adult and children) were slightly lower while the children had higher values as observed in CDIs and HQs (Fig. 3).

5. Discussion

The spatio-temporal variations of heavy metals in the Anya River at Nnono-Oboro were likely influenced by interplay between anthropogenic activities in the larger Anya River watershed and season. The river drains a research institute, a university and a number of communities. In related studies in Nigeria and beyond, higher values were recorded in the dry season (Nnaji and Arinze, 2022; Abebe et al., 2023; Adetunji et al., 2025). Higher values recorded in the dry season could be attributed to little or no rainfall, reduction in flow velocity and elevated temperatures with associated evapotranspiration (Anyanwu and Umeham, 2020). Human dependence on the river for drinking and domestic purposes is usually higher in the dry season because there are a few private and commercial boreholes in the community and not many can afford it. The implication is that users of the river will be exposed to higher concentrations of the metals; leading to dire consequences.

The concentrations of iron were higher than the drinking water limit (SON, 2015) and risk quotient showed that the concentrations were 3.27 – 3.87 times higher than the acceptable limit. The RQ values were greater than 1 and such higher values are indications of greater potential risks (Gu, 2021) that required further investigation. Hence, Fe was considered for health risk assessment. The highest value recorded in station 3 (January 2024) could be as a result of runoff from the first rain of the year that occurred a day before sampling. Stormwater and runoffs discharge into the river at a point in between stations 2 and 3. Rainfall event after a period of dryness can mobilize organic and inorganic pollutants into surface water with considerable risk to water quality (Qiu et al., 2021). On the other hand, the lowest value recorded in Station 1 (July 2024) could be as a result of dilution from runoff due to increased rainfall. July is one of the peaks of rain in the region. Within the watershed, Anyanwu et al. (2022) recorded lower iron values (0.10 – 0.91 mg/L) in Anya stream, Umudike while Adetunji et al. (2025) recorded higher values (0.34 – 3.78 mg/L) in Azueke stream, Umuahia. Anya and Azueke streams are tributaries of Anya River around the Research Institute and University. Elsewhere, Abebe et al. (2023) recorded lower values of 0.01 – 0.90 mg/L in Awash River basin in Ethiopia.

The concentrations of manganese (Mn) also exceeded the limit set by SON (2015) for drinking water and risk quotient showed that the concentrations were 2.60 – 3.35 times higher than the acceptable limit. The RQ values were greater than the threshold value of 1. Hence, Mn was considered for health risk assessment. The highest value recorded in station 3 (April 2024) could be as a result of allochthonous input from a rainfall event that occurred a few days to sampling while the lowest value recorded in station 1 (July 2024) could be due to dilution as in Fe. Within the watershed, lower values were recorded. For example, 0.04 – 0.31 mg/L and 0.10 – 1.05 mg/L were recorded in Anya stream, Umudike by Anyanwu et al. (2022) and Adetunji et al. (2025) in Azueke stream, Umuahia respectively. Elsewhere, Abebe et al. (2023) recorded lower Mn values of 0.003 – 1.25 mg/L in Awash River basin in Ethiopia while Farounbi et al. (2022) recorded higher values 0.0007 – 4.19 mg/L in Swartkops River in Eastern Cape Province, South Africa.

The concentrations of chromium (Cr(VI)) also exceeded the limit set by SON (2015) for drinking water and risk quotient showed that the concentrations were 5.00 – 6.20 times higher than the acceptable limit. The RQ values were greater than the threshold value of 1. Hence, Cr (Cr(VI)) was considered for health risk assessment. The highest value recorded in station 3 (January 2024) could be attributed to the effect of the first rain of the year as observed in Fe. On the other hand, the lowest value recorded in Station 1 (June 2024) could be due to dilution resulting from onset of the rains. Within the watershed, lower values were recorded. For example, Anyanwu et al. (2022) recorded 0.02 – 0.11 mg/L in Anya stream, Umudike and Adetunji et al. (2025) recorded 0.04 – 0.37 mg/L in Azueke stream, Umuahia. Elsewhere, Abebe et al. (2023) recorded lower Cr(VI) values of 0.0002–0.036 mg/L in Awash River basin in Ethiopia while Farounbi et al. (2022) recorded higher values of 0.0003 – 9.53 mg/L in Swartkops River in Eastern Cape Province, South Africa.

The concentrations of cadmium (Cd) also exceeded the limit set by SON (2015) for drinking water and risk quotient showed that the concentrations were 33.33 – 40.00 times higher than the acceptable limit. The RQ values were greater than the threshold value of 1 by wide margin. Such RQ values were considered very high; indicating greater potential risks (Gu, 2021). Hence, Cd was considered for health risk assessment. The lowest value recorded in Station 2 (September 2024) could be attributed to dilution. September is one of the peaks of rain in the region. On the other hand, the highest recorded in Station 1 (April 2024); attributable to the same factors observed in Mn. Within the watershed, lower values were recorded. For example, Anyanwu et al. (2022) recorded 0.01 – 0.07 mg/L in Anya stream, Umudike and Adetunji et al. (2025) recorded 0.03 – 0.23 mg/L in Azueke stream, Umuahia. Elsewhere, Farounbi et al. (2022) recorded higher values of 0.00 – 4.28 mg/L in Swartkops River in Eastern Cape Province, South Africa.

The concentrations of zinc (Zn) were lower than the limit set by SON (2015) for drinking water and the risk quotient was less than 1 (0.24 – 0.29 times lower). Hence, it was not considered for health risk assessment. The lowest value recorded in Station 1 (July 2024) could be attributed to dilution, while the highest in station 3 (March 2024) could be due dry season effect. During the dry season, there is little or no allochthonous input coupled with concentration due to little or no rainfall, reduction in flow velocity and elevated temperatures with associated evapotranspiration (Anyanwu and Umeham, 2020). Within the watershed, Anyanwu et al. (2022) recorded lower values (0.07 – 0.52 mg/L) in Anya stream, Umudike while Adetunji et al. (2025) recorded higher values (0.22 – 1.87 mg/L) in Azueke stream, Umuahia. Elsewhere, Farounbi et al. (2022) recorded lower values of 0.03 – 0.30 mg/L in Swartkops River in Eastern Cape Province, South Africa.

The concentrations of nickel (Ni) exceeded the limit set by SON (2015) for drinking water except for stations 1 (June and July 2024) and 2 (August 2024). Risk quotient showed that the concentrations were 4.00 – 4.50 times higher than the acceptable limit. The RQ values were greater than the threshold value of 1. Hence, Ni was considered for health risk assessment. The lowest values recorded in Stations 1 (June and July 2024) and 2 (August 2024) could be attributed to dilution. On the other hand, the highest recorded in Station 1 (April 2024); attributable to the same factors observed in Mn and Cd. Within the watershed, lower values were recorded. For example, Anyanwu et al. (2022) recorded 0.01 – 0.05 mg/L in Anya stream, Umudike and Adetunji et al. (2025) recorded 0.01 – 0.18 mg/L in Azueke stream, Umuahia. Elsewhere, Farounbi et al. (2022) recorded higher values of 0.004 – 3.57 mg/L in Swartkops River in Eastern Cape Province, South Africa.

The concentrations of copper (Cu) were also lower the limit set by SON (2015) for drinking water and the risk quotient was less than 1 (0.37 – 0.46 times lower). Hence, it was not considered for health risk assessment. The highest and lowest values were also recorded in Stations 3 (April 2024) and 1 (July 2024); attributable to the same factors observed in Mn, Cd and Ni. Within the watershed, lower values were recorded. For example, 0.04 – 0.19 mg/L and 0.06 – 0.84 mg/L were recorded in Anya stream, Umudike by Anyanwu et al. (2022) and Adetunji et al. (2025) in Azueke stream, Umuahia respectively. Elsewhere, Farounbi et al. (2022) recorded higher values of 0.004 – 4.35 mg/L in Swartkops River in Eastern Cape Province, South Africa.

The concentrations of lead (Pb) were higher than the drinking water limit (SON, 2015) and risk quotient showed that the concentrations were 16.00 – 18.00 times higher than the acceptable limit. The RQ values were greater than the threshold value of 1 by high margins. The RQ values were considered high. Higher RQ values are indications of greater potential risks (Gu, 2021). Hence, Pb was considered for health risk assessment. The lowest value recorded in Station 1 (June and July 2024) could be attributed to dilution; while the highest was also recorded in Station 1 (April 2024); attributable to the same factors observed in Mn, Cd, Ni and Cu. Within the watershed, lower values were recorded. For example, Anyanwu et al. (2022) recorded 0.01 – 0.09 mg/L in Anya stream, Umudike and Adetunji et al. (2025) recorded 0.03 – 0.31 mg/L in Azueke stream, Umuahia. Elsewhere, Munene et al. (2023) recorded lower value of 0.06 – 0.23 mg/L in Sosian River, Eldoret, Kenya while Farounbi et al. (2022) recorded higher values of 0.00 – 3.91 mg/L in Swartkops River in Eastern Cape Province, South Africa.

The water was highly polluted because all the WPI values were >1. Water is classified as WPI<0.5 (excellent quality), 0.5>WPI<0.75 (good quality), 0.75>WPI<1 (moderately polluted) and WPI>1 (highly polluted) (Hossain and Patra 2020). Therefore, the water is not suitable for drinking. Elsewhere in the watershed, Adetunji et al. (2025) recorded lower WPI values (5.02 – 6.57) in Azueke stream, Umuahia.

There were slight variations in the chronic daily intake (CDI) values among the metals. The values generally increased from upstream (station 1) to downstream (station 3) in relation to the heavy metal content. Studies have shown that heavy metal content usually increase from upstream to downstream (Shanbehzadeh et al., 2014; Tukura et al., 2022). Children recorded higher values than the adults as observed in related studies (Ugwu et al., 2022; Abebe et al., 2023; Munene et al., 2023; Fahimah et al., 2024; Adetunji et al., 2025). This could be attributed to the fact that they have shorter heavy metal exposure duration, lower body weights and consume more water in relation to their body weight (Fahimah et al., 2024). WHO (2017) stated that contaminant uptake among children is higher due to higher age-dependent dose coefficients; though their mean water consumption volume may be lower. The high metabolic rates and developing systems of children can also influence their capacity to handle pollutants (USEPA, 2023). The values of Fe and Mn exceeded their respective limits set by SON (2015) but their CDI values were lower than their respective oral reference doses (RfD). Consequently, the two metals did not pose any health risk. Reference dose gives an idea of the daily exposure to exogenous chemicals that humans (including sensitive groups) can be exposed to without any manifestation of adverse health effect during their lifetime (Anderson et al., 2024). Reference dose ensures the safety of products consumed by humans. The other metals (Cr (Cr(VI)), Cd, Ni and Pb) exceeded both the acceptable limits set by SON (2015) and their respective reference doses. Consequently, these metals may pose serious health risks to people using the water for drinking especially children. Chromium, cadmium and nickel are carcinogens (Chen et al., 2019; Balali-Mood et al., 2021). They are classified as category 1 carcinogens by the International agency for Research on Cancer (IARC, 2012). Apoptosis, oxidative stress, DNA damage response leads to a number of bone and kidney diseases, lung cancer, skin allergy with dermatitis as a result of Cr(VI) and Cd toxicities (Kim et al., 2015). Ni toxicity is also associated with apoptosis, oxidative stress, DNA methylation, and DNA damage as well as toxicity in lung, nose, skin, kidney and liver (Kim et al., 2015). On the other hand, Pb is not a carcinogen but poses serious health threats to humans (Rehman et al., 2019). Children less than 6 years are more susceptible though the threats are applicable to all age groups (Akhtar et al., 2022). Elevated concentrations of Pb have led to severe health issues among children especially in developing countries with no or weak regulatory framework (Ferronato and Torretta, 2019).

Hazard quotients (HQs) and Hazard index (HI) were higher among children as in the case of CDI; attributed to the factors influencing the CDI. This trend was also reported related studies within and outside Nigeria (Abebe et al., 2023; Munene et al., 2023; Fahimah et al., 2024; Adetunji et al., 2025). The HQ values for Fe and Mn were lower than the threshold value (1) among children and adult and in all the stations. However, all the HQ values for Cr(VI) Cd, Ni and Pb were higher than the threshold value (1) among the children and adult and in all the stations. There is no problem with non-cancer risk when HQ values are less than 1. However, when HQ values exceeds 1, a non-cancer health risk has been activated and the pollutant concentration may be harmful to humans and should not be ignored (Sharma, 2020; ATSDR, 2022). The HI values also exceeded the threshold value of 1 among the children and adult and in all the stations; indicating that the water is not potable based on the heavy metal content. The values were higher than 1.249 - 3.564 (Adult) and 2.913 - 8.314 (Children) recorded by Munene et al. (2023) in Sosian River, Eldoret, Kenya. However, Eid et al. (2024) recorded very high values for Adult (1.6-142.1) and children (6.2-542.6) in Siwa Oasis in Egypt.

6. Conclusion

This study has shown that based on the concentration of the heavy metals, water pollution index, risk quotient and health risk assessment, the water of Anya River at Nnono-Oboro was not potable. All the metals evaluated exceeded limits for drinking water except copper and zinc. The concentrations of chromium (VI), lead, nickel and cadmium influenced observed adverse health risk and the burden of the risk is more on the children. Drinking water from the river is not advisable because of the high hazard index and associated health risk recorded in all the stations. However, it can be used for other domestic purposes like washing, cleaning and irrigation. Anthropogenic activities in the greater Anya River watershed and season were responsible the heavy metal content and the indices. In view of importance of Anya River to the community, it is recommended that regular monitoring should be carried out while community education should be used to create awareness of the dangers of drinking the water. Community-based water supply scheme could be provided to reduce their dependence on the river.

Study Limitations

The community and river were remotely located; limiting the accessibility to only use of motorbikes. This limited the time of sample collection, number of field replicates and increased the cost of sample collection. However, as part of the quality assurance, the samples were immediately acidified after collection to minimize changes in the content. Community perception of the study was also a factor because the sampling was often interrupted to explain and allay their fears.

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The authors declare that there is not any conflict of interests regarding the research and publication of this manuscript.

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No required

Data/materials/code availability:

The datasets supporting the findings of this study are provided as supplementary material available online

Author's Contribution:

The authors confirm contribution to the paper as follows: study conception and design: EDA, LAO; field studies: EDA, LAO, AGS; data analysis and validation, EDA, AGS; draft manuscript preparation: EDA, LAO, AGS. All authors reviewed the results and approved the final version of the manuscript.

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