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ORIGINAL ARTICLE

Exposure risk to heavy metals through surface and groundwater used for drinking and household activities in Ifite Ogwari, Southeastern Nigeria

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Abstract
Surface and groundwater are the most common sources of water in Nigeria's rural communities, which are used for a variety of purposes ranging from farming to industrial processes and other domestic household activities including drinking. Water that contains heavy metals in excess of the maximum permitted levels poses a risk to human health. This study aims to evaluate the levels of heavy metals in surface and groundwater in Ifite Ogwari, a rural community in Anambra State, Southeast Nigeria, as well as their ecological indices and human health risks assessment. The concentration levels of Ni, Cr, Cd, Pb, Zn, Fe, Mn, and Cu were determined in fifteen water samples from the major water sources in the study area, viz., streams, river, and hand-dug wells. The water samples were collected using precleaned 500 cm^3 glass bottles and were analyzed using Atomic Absorption Spectroscopy (AAS) technique. The results showed that four metals (Cr, Cu, Mn, and Pb) out of the eight heavy metals were not detected in all the samples. The concentration levels of total Ni had a range of 0.029–0.11 mg/L with highest concentration occurring at *Isiachala* stream, *Onowulugbe* well, and *Omambala* river (0.11 mg/L). The Cd levels in the water samples had a range of 0.001–0.036 mg/L, with *Isiachala* and *Iyiutu* having the highest values (0.036 mg/L). The concentration of Fe ranged from 0.01 to 0.047 mg/L. Mn was detected at a concentration level of 0.003 mg/L in *Iyiutu* stream only. The Pearson correlation deduced a strong correlation (> 0.75) and a medium correlation (0.50–0.75) for sample locations and analytes, while three factors (principal component analysis) were produced, which indicates the influence of anthropogenic release rather than natural release. Ecological indices showed the impact of multi-elemental matrices on the ecology, while health risk assessments showed that there was no adverse cancer risk or non-cancer risk across respondents (adults and children). The obtained results showed that anthropogenic release has an extensive mobility influence on the natural level of metals in surface and ground water in Ifite Ogwari, and so proper treatment is advocated. This study has shown that the water sources from Ifite Ogwari pose no adverse health risk to the residents. Consequently, additional research on Ifite Ogwari water is needed to characterize "forever chemicals," per- and polyfluoroalkyl substances (PFAS) which are ubiquitous, cancerous and have been linked to reproductive and immune system harm, and suggest routes for remediation.

Keywords Portable water · Toxic metals · Multivariate · Ecological indices · Public health

Introduction

Water is a basic human amenity and, as such, is extremely important for survival. It is used for a variety of applications, including residential functions, agricultural output, and industrial activities. Despite its importance for life, water is inadequately managed in many regions of the world (Fakayode 2005). Water is a good solvent, and as a result, it dissolves and contains mineral components and other substances that it leaches out when it comes into contact with them. Water contamination in a given location is always proportional to the level of contamination in the surrounding environment (Khan 2011). Rainwater gathers pollutants from the atmosphere as it drips down. As a result, pollutants from surface run-off, sewage discharges, and industrial effluents gather in rivers and streams as they move. Rivers and streams are therefore key sources and conduits for anthropogenic metal mobility and transportation (Stark et al. 2001).

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More than a billion people throughout the world lack access to safe drinking water, with more than 300 million of them residing in rural parts of sub-Saharan Africa (Bhatia 2009). Ifite Ogwari, a rural community in Anambra State, Southeastern Nigeria, is characterized by a scarcity of potable water. Because of this, residents must rely on streams, natural ponds/lakes, shallow hand-dug wells, and rainwater collection to provide their whole water demands. It is well known that water resources in rural regions of Nigeria are prone to contamination, either as a result of residents' poor hygiene or as a result of agricultural and local industrial activities (Bolawa et al. 2014). The threat of contaminated drinking water to one's health is tremendous as many infectious diseases, for example, are spread through water contamination. Drinking contaminated water causes the deaths of five million children each year and sickens one-sixth of the world's population (Essien and Bassey 2012). Heavy metal contamination of surface and groundwater resources is increasingly becoming a major global environmental problem due to their refractory characteristics and bioaccumulation, as evidenced by numerous previous studies such as Adefemi and Awokunmi (2009), Essien and Bassey (2012), Afiukwa et al. (2010), Mudgal et al. (2010), Nkuma (2000). Due to the health dangers associated with their presence, heavy metal pollution of water resources has recently become a focus of public attention (Mitra et al. 2022; Sarker et al. 2022; Balali-Mood et al. 2021). Agricultural activities, houses, local markets, abattoirs, and traditional businesses like blacksmithing, foundries, and metal and crude oil odors have all been identified as substantial anthropogenic sources of heavy metals in the rural aquatic environment (Mudgal et al. 2010). All of these activities degrade the quality of water sources by introducing dangerous toxic metals into them.

Heavy metals form a collection of contaminants that have been discovered as posing a major threat to aquatic habitats and humans, even at trace levels, and are known for their toxicity and environmental durability (Masindi and Muedi 2018). It is widespread knowledge in Nigeria that the bulk of water sources available to locals are contaminated by heavy metals (Adefemi and Awokunmi 2009). As a result, around 60% of Southeastern Nigerians who live in rural areas consume water that is contaminated with germs, heavy metals, and other contaminants that can cause a variety of ailments. Heavy metal contamination and its harmful effects on living species in the aquatic environment and on humans have been studied extensively all over the world and reported by many scholars (Nkuma 2000; Sada and Odemerho 1988; Okafor et al. 2021).

Some hazardous metals are naturally needed for healthy functioning at minute amounts and are referred to as trace elements (iron, copper, manganese, and zinc). These elements are widely distributed in water, beverages, soil, foodstuffs, fruits, and vegetables (Okafor et al. 2016; 2020; 2021a; Nduka et al. 2006; 2008; Orakwue et al. 2021), and are commonly discharged through mining and industrial wastes, automotive emissions, lead-acid batteries, fertilizers, paints, and treated woods (Wuana and Okieimen 2011). Because of their non-biodegradability and lengthy residence period in the environment, hazardous metals like Pb, Cr, and Cd are commonly referred to as "chemical time bombs" (Stiglian et al. 1991). These metals have a direct impact on public health because they are quickly absorbed into the body by oral consumption, skin contact, and/or inhalation (Abrahams 2002). The potential harmful metals' estimated daily intake rate from multiple pathways (food, soil, water, and air) can be established through ingestion, inhalation, and skin contact (Nadal et al. 2005). The hazard quotient (HQ) developed by the United States' Environmental Protection Agency (US EPA 2000a; b) has long been used to quantify the possible health risk associated with long-term exposure to hazardous metals in various media. Although these potentially harmful metals occur naturally in the earth's crust, uncontrolled application of agrochemicals, refining, smelting, and burning of fossil fuel and sewage sludge tend to enrich agricultural soil and subsequently water bodies (Gimeno-Garcia et al. 1996; Omokpariola 2021).

Accurate and timely information on water quality is required to develop solid public policy and efficiently conduct the water quality improvement program. The presence of dead vegetation, heavy metal leachates from solid waste dumps, household and industrial sewage, and surface runoff from agricultural farms necessitates research into the heavy metal content of these bodies as drinking water sources. Pollution of these bodies of water first affects the chemical quality of the water, then gradually destroys the community, causing the delicate food web to be disrupted. Because of the ability of water to spread diseases across a wide population, compliance with the heavy metal standard is of particular significance. Although regulations differ from place to place, the goal is to keep the risk of waterborne diseases to a bare minimum while still being pleasant to drink, which means it must be healthy and free of contaminants. As a result, ensuring high-quality drinking water is a critical component of public health, environmental conservation, and long-term growth.

Although Ifite Ogwari is a rural village with little or no industrial activity, it is home to a large number of roadside mechanics, welders, and other artisans. The village is crossed by a major federal route and a state road, which both connect Anambra State to Adani Town in Enugu State (Ihedioha et al. 2021), and within the community, there are a few modest asphalted streets. The use of agrochemicals, indiscriminate dumping of metal-containing wastes, vehicular emissions, and sewage water irrigation are all on the rise in Ifite Ogwari. As a result, it is critical to keep track of the water sources used by locals in Ifite Ogwari, in particular, and Nigeria as a whole. Consequently, Okafor et al. (2022a) reported polycyclic aromatic hydrocarbons (PAHs) contamination of water sources in Ifite Ogwari as other scholars had previously reported heavy metal contamination of numerous water sources in Nigeria (Ibe et al. 2021) and beyond (Vetrimurugan et al. (2017), Enriqueta et al. (2017) Saeed et al. 2014). Mwiathi et al. (2022) investigated the occurrence of geogenic fluoride in shallow aquifers in Kenya. Studies on human health risk exposure to toxic and harmful metals in Pakistan abound (Ali et al., 2021; Iqba et al., 2021; Jehan et al. 2019; Khattak et al. 2021; Noor et al. 2022; Rashid et al. 2021; Rashid et al. 2020; Rashid et al. 2019a; b; Talpur et al. 2020; Ullah et al. 2021). In India, drinking suitability of water resources has been researched extensively (Wagh et al. 2019; Wagh et al. 2020; Kadam et al., 2021; 2022).

Nonetheless, no research of this kind has been attempted on surface and groundwater in Ifite Ogwari, Anambra State, southeast Nigeria and therefore, the need to study exposure risk to heavy metals and its health implications to the residents of Ifite Ogwari community becomes very vital and hence the current study. The aim of the study was to determine the levels of some heavy metals (Ni, Mn, Cr, Cd, Pb, Zn, Fe, and Cu) in surface and groundwater in Ifite Ogwari and analyze the health risks of consuming them by calculating daily oral consumption, hazard quotient (HQ), and total hazard index (THI).

Materials and methods

Study area

Figure 1 illustrates the study area and sample location points as described in our previous work (Okafor et al 2022a). Briefly, Ifite Ogwari, 45 km from Awka, the capital of Anambra State (Ewuim et al. 2018), is located between latitude 6.6041° North and longitude 6.9507° East, at an elevation of 91 m above sea level (Wikipedia 2018). Ifite Ogwari is located on the banks of the Omambala river and endowed with thick foliage and fertile fields suitable for the growing of food crops such as rice, maize, yam, cassava, okro, and plantain making it a perfect setting for Nnamdi Azikiwe University's Faculty of Agriculture. The overall rainfall averages for the year and month are 5798.78 mm and 1739.62 mm, respectively (Ifeka and Akinbobola 2015). With tropical forests as the dominant vegetation type, the lowest and highest temperatures are 25.4 °C and 30.6 °C, respectively (Iheke and Nwaru 2009; NIMET 2014). The community has a 7-month rainy season (April–October) with a break around July/August and a 5-month dry season (November to March), with harmattan occurring at some points during the dry season. Many rivers and streams run through the area, all of which are part of the Anambra river system which had been identified by Crosskey (1981).

Geologically, Ifite Ogwari is located within the Anambra Basin as depicted in Fig. 2. The Anambra Basin was deposited and filled in two sedimentary phases: transgression and sea regression. The transgression, which occurred during the Campanian—Maastrichtian period, gave rise to deposition of Nkporo Shale, Mamu Formation, Ajalli Sandstone, Nsukka Formation and Imo Shale (Nwajide, 2013; Anakwuba et al., 2021). The study area, Ifite Ogwari is underlain by the Palaeocene Imo Formation (Fig. 2). The Imo Formation is the basal unit of the Niger Delta Basin. The Formation is essentially a mudrock unit consisting of dark gray to bluish gray shale, with occasional admixtures of clay, ironstone, thin sandstone bands, and limestone intercalations (Nwajide, 2013; Anakwuba et al., 2021).

Hydrogeologically, a sand member of the Imo Shale known as the Ebenebe Sandstone usually constitutes of semi-confined to confined aquifers with some boreholes

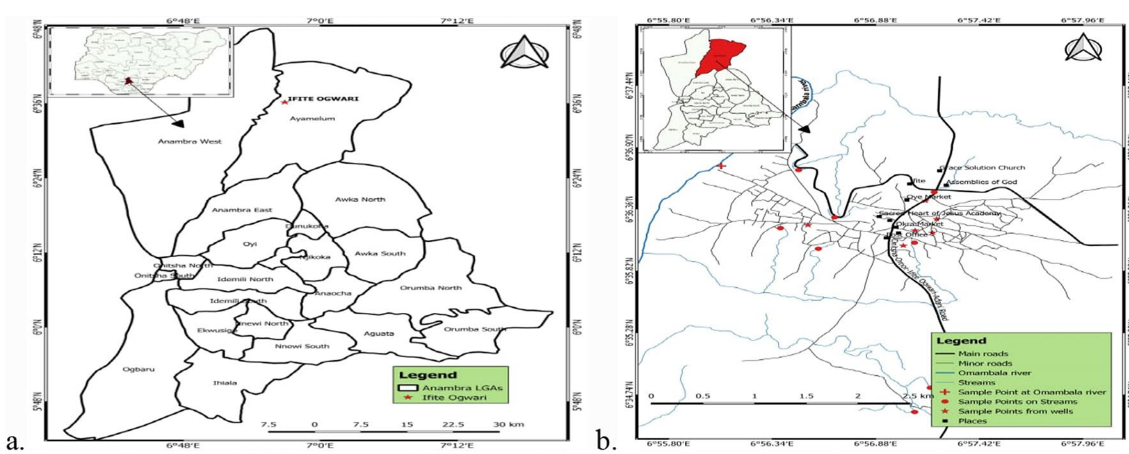

Fig. 1 **a** Map of Anambra State, Nigeria showing Ifite Ogwari, **b** map of Ifite Ogwari showing sample collection points

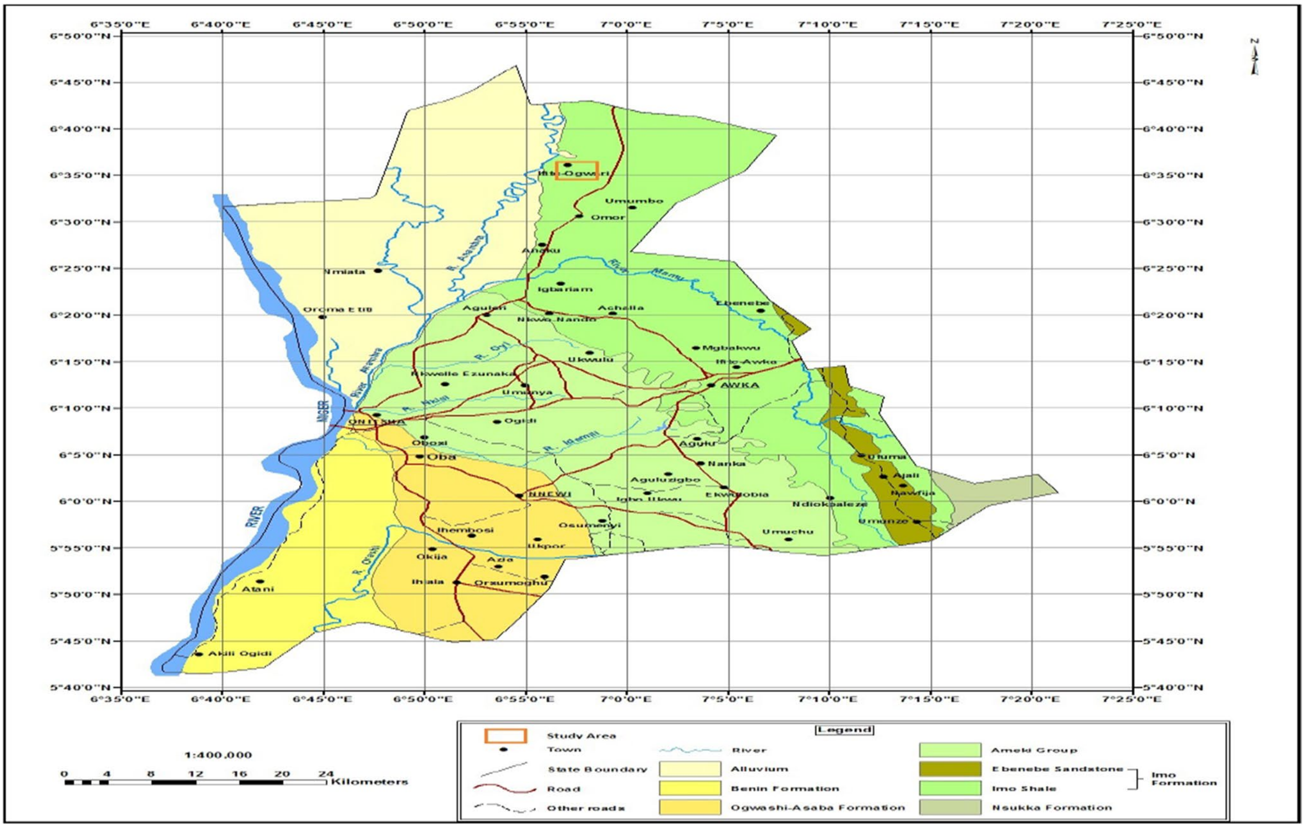

Fig. 2 Geologic map of Anambra showing the major lithostratigraphic units

existing under artesian to sub-artesian conditions and greater depths to aquifers (Nwajide, 2013; Anakwuba et al., 2021). The Imo Shale constitutes the aquitard within the study area.

Streams, rivers, and shallow hand-dug wells provide practically all of the water needs for the residents as can be seen in Fig. 3. These people are 100% agriculturists, traditional industrialists, and even civil servants engage in some type of agricultural activity.

Sampling

From Ifite Ogwari, Anambra State, Nigeria, fifteen water samples were collected [9 surface: *Isiachala* (SA), *Iyiutu* (SB), *Ube* (SC), *Ahala* (SD), *Tabasi* (SE), *Nabaloku* (SF), *Atammele* (SG), *Ogbu* (SH), and *Omambala* (RA) and 6 hand-dug wells: *Igbazine* (WA), Double (WB), *Ogba* (WC), *Onowulugbe* (WD), Orator (WE) and Commodore (WF)]. Water sources were chosen for examination because they are available to the community at all times of the year. The sampling sites information is shown in Fig. 2 and Table 1.

a b c

Fig. 3 **a** View of Ogbu stream, **b** woman fetching from Commodore hand-dug well **c** boy fetched from Ahala stream

Table 1 Selected points for water sampling in Ifite Ogwari, Anambra State

SN	Sampling point	Sample Code	Coordinates
1	Isiachala stream	SA	06° 34.589′ N, 06° 57.083′ E
2	Iyiutu stream	SB	06° 14.816′ N, 07° 07.287′ E
3	Ube stream	SC	06° 36.702′ N, 06° 56.478′ E
4	Ahala stream	SD	06° 36.289′ N, 06° 56.666′ E
5	Tabasi stream	SE	06° 36.015′ N, 06° 56.581′ E
6	Nabaloku stream	SF	06° 36.195′ N, 06° 56.383′ E
7	Atammele stream	SG	06° 36.509′ N, 06° 57.185′ E
8	Ogbu stream	SH	06° 36.067′ N, 06° 57.082′ E
9	Omambala river	RA	06° 36.737′ N, 06° 56.074′ E
10	Igbazine hand-dug well	WA	06° 36.221′ N, 06° 56.527′ E
11	Double hand-dug well	WB	06° 36.434′ N, 06° 57.139′ E
12	Ogba hand-dug well	WC	06° 36.274′ N, 06° 57.198′ E
13	Onowulugbe hand-dug well	WD	06° 36.154′ N, 06° 57.176′ E
14	Orator hand-dug well	WE	06° 36.174′ N, 06° 57.085′ E
15	Commodore hand-dug well	WF	06° 36.041′ N, 06° 57.024′ E

Samples were collected on February 20, 2020, using previously cleaned glass bottles. At each step of the collection, the bottle was rinsed twice with the water sample to be collected. Streams were designated (SA–SH), river (RA), and hand-dug wells (WA–WF). The water sample sites were geo-referenced using a Garmin GPS map. The samples were packaged and delivered to the Nigerian Institute of Oceanography and Marine Research's Central Laboratory at Victoria Island, Lagos, for heavy metal analysis.

Quality control and heavy metal determination

The analyses required high-quality analytical reagents, which were acquired from BDH Chemical Ltd in the United Kingdom and Sigma-Aldrich Chemie GmbH in Germany. Detergents and deionized water were used to wash the glassware and sample bottles, which were thereafter soaked overnight with a solution of 10% HNO_3 in a 1% HCl solution, followed by rinsing with deionized water. Heavy metal analysis by Atomic Absorption Spectrophotometric technique as described by several authors (Assubaie 2015; Ipeaiyeda 2017; Okafor et al. 2022a; b) was adopted and modified. Briefly, 10 cm^3 of perchloric acid and 10 cm^3 concentrated HNO_3 were added to 2 cm^3 of the sample in a 250 cm^3 beaker. This was boiled in a fume cupboard on a hot plate until white vapors began to emerge. The digestive system was then recharged and heated until white fumes were released. The addition of 20 cm^3 of deionized water was then made. The mixture was then boiled for another 20 min until it was particle-free. The digested sample was brought down and cooled to room temperature under the hood. The filtrate was collected in a 50 cm^3 volumetric flask after being filtered through No. 11 Whatman filter paper. Before the combined filtrate was made up to mark and placed into a sample container, 20 cm^3 of deionized water was used to rinse the filter paper. Standards were made from the salts of the metals to be analyzed, and lamps for the analysis were set up. This was done for Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn. The diluents of the sample were aspirated into an Agilent AA500F Atomic Absorption Spectrophotometer.

All of the samples were examined in triplicate, and the metal concentrations were averaged out. The reagent blank, as well as reference material, were analyzed for quality control. During the concentration computation, a blank reading was used to make necessary corrections. The concentrations of the investigated metals indicated in the blank tests were taken into account in the final results for the respective heavy metals. The amount of metal present in each sample was estimated by determining concentration based on absorbance following Beer-Lambert's law.

Method validation

Limit of detection (LOD), limit of quantification (LOQ), precision, and recovery were evaluated according to the recommendations of the Eurachem Guide (Eurachem 2014). The recommendation, which had previously been utilized by scholars such as dos Santos et al. (2021) and Okafor et al. (2022a) was implemented with adjustments. The analytes' calibration curves were created in triplicate using deionized water spiked with heavy metal solutions at five concentration levels which were 1.0, 5.0, 10.0, 15.0 and 20.0 $\mu g\ L^{-1}$). LODs and LOQs were determined by analyzing ten blanks. To calculate the LOD, the standard deviation of the replicate's results was multiplied by three and divided by the slope of the calibration curve. The LOQ was computed by multiplying the LOD by 3.33. At concentrations of 5.0 and 15.0 $\mu g\ L^{-1}$, intra-day precision was tested in three replicates at each concentration. On two consecutive days, inter-day precision was examined. Five repetitions were used to assess recovery at a concentration of 10.0 μg L^{-1}.

Heavy metal pollution index

The appropriateness of water is determined by the permissible standards for drinking water set by various organizations and governments. However, a comprehensive understanding of the degree of contamination based on all heavy metals is not possible. As a result, numerous studies have employed the water quality index (WQI) to estimate the overall quality of water based on heavy metals (Horton 1965; Brown et al. 1970).

The WQI values were classified as; WQI < 50 indicates excellent water quality; 50 < WQI ≤ 100 means good water quality; 100 < WQI ≤ 200 indicates poor water quality; 200 < WQI ≤ 300 implies very poor water quality, and WQI > 300 indicates that the water is unfit for consumption (Ramakrishnaiah et al. 2009).

The water quality index was calculated using Eq. (1) (Chatterjee and Raziuddin 2002; Lele et al. 2018).

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi} \tag{1}$$

where Wi is the unit weightage of the 'i'th heavy metal, n is the number of heavy metals considered and Qi is the sub index of the 'i'th heavy metal.

The unit weight, Wi, is calculated by

$$Wi = \frac{K}{Si} \tag{2}$$

where K is the proportionality constant, Si is the standard permissible limit in water for the 'i'th heavy metal proportionality constant, K is calculated by,

$$K = 1/\sum_{i=1}^{n} \frac{1}{Si} \tag{3}$$

and

$$\sum_{i=1}^{n} \frac{1}{Si} = \frac{1}{S1} + \frac{1}{S2} + \frac{1}{S3} + \ldots + \frac{1}{Si} \tag{4}$$

where S_1, S_2, S_3, etc., represent standards for different heavy metals in water such as manganese, cadmium, copper, lead, etc.

The sub index, Qi, is calculated by

$$\sum_{i=1}^{n} \frac{(Mi - Ii)}{(Si - Ii)} \times 100 \tag{5}$$

where Mi is the monitored value of heavy metal of the 'i'th heavy metal, Ii is the ideal value of the 'i'th heavy metal based on international limits for drinking water and Si is the standard value of 'i'th heavy metal. Table 2 depicts the limits and weight of heavy metals used for WQI calculation.

Multivariate statistical analysis

The utilization of multivariate statistics has the potential for source identification in water quality evaluation in that dataset are analyzed using XL Stat Add-ins for Microsoft ® Excel Package [v 2019] (Omokpariola et al. 2020; Egbueri et al. 2019; Wagh et al. 2018). In this study, Pearson correlation and factor analysis were conducted as 0.30–0.50 (low aggregate), 0.50–0.75 (medium aggregate) and 0.75–1.00 (high aggregate) (Ojaniyi et al. 2021; Barzegar et al. 2019).

Ecological assessment

In this study, several data sets were utilized to evaluate contamination factor (CF), degree of contamination (Deg C), modified degree of contamination (mC_{Deg}), pollution load index (PLI), Nemerow pollution index (NPI) and Potential ecological risk index (PERI).

Contamination factor

Contamination Factor (CF) is the extent of pollution of contaminant of interest, it is expressed as:

$$\mathrm{CF} = \frac{\text{chemical contaminant of interest}}{\text{Background value using WHO standard}} \tag{6}$$

Table 2 Limits and weight of heavy metals used for WQI calculation *Source*: Vetrimurugan et al. (2017)

Heavy metal	Standard value, Si (mg/L)	Ideal value, Ii (mg/L)	Unit weight, Wi
Ni	0.02	0	3.8×10^{-5}
Mn	0.3	0.1	5.7×10^{-4}
Cr	0.05	0	9.5×10^{-5}
Cd	0.003	0	5.7×10^{-6}
Pb	0.01	0	1.9×10^{-5}
Zn	15	5	2.8×10^{-2}
Fe	0.3	0.1	5.7×10^{-4}
Cu	1.5	0.05	2.8×10^{-3}

The background values of selected heavy metals are Ni = 0.07; Cr = Zn = 0.05; Cd = 0.003; Pb = 0.01; Fe = 0.3; Cu = 2.

Degree of contamination

This is the summation of contamination factor of all chemical contaminants in study site. It is calculated as follows

$$C_{\text{deg}} = \sum (\text{CF}) = \text{CF}_1 + \text{CF}_2 + \text{CF}_3 + \ldots + \text{CF}_n \tag{7}$$

Modified degree of contamination

This is the average effect of all chemical contaminants of interest, the advantage of mC_{Deg} is that it quantifies the chemical contaminants into a composite aggregate to derive salient information about the study site.

$$\text{mC}_{\text{Deg}} = \frac{1}{n} \sum (\text{CF}) \tag{8}$$

where n is the sum total of chemical contaminant and CF is the contamination factor.

Pollution load index

PLI is the geometric mean of CF value to the nth number of chemical contaminants of interest, it is given as:

$$\text{PLI} = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)^{1/n} \tag{9}$$

where n is the sum total of chemical contaminants and CF is the contamination factor. The PLI gives the level of pollution classified as PLI < 1 (no pollution), 1 < PLI < 2 (modest pollution), 2 < PLI < 3 (high pollution), and 3 < PLI (extremely high pollution).

Nemerow pollution index

It is the complete effect of chemical constituents in the study site which is given as:

$$P_{\text{N}} = \sqrt{\frac{\overline{CF}^2 + CF_{\text{max}}^2}{2}} \tag{10}$$

where P_{N} is the nemerow pollution index, $\overline{CF}^2$ is arithmetic mean of contamination factor of all chemical contaminants, CF^2_{max} is the maximum contamination factor among all chemical contaminants. P_{N} is graded as $P_{\text{N}} < 1$ (unpolluted), $1 \le P_{\text{N}} < 2.5$ (slightly polluted), $2.5 \le P_{\text{N}} < 7$ (moderately polluted) and $P_{\text{N}} > 7$ (heavily polluted).

Potential ecological risk index (PERI)

PERI assesses the toxicity factor of a particular chemical contaminant of interest, where the definite contamination status is evaluated in respect to the ecosystem. It is expressed as:

$$\text{PERI} = \sum E_{\text{r}} = \text{TF} \times \text{CF} \tag{11}$$

where E_{r} is ecological risk index of different chemical contaminant, TF is toxicity factor of each chemical contaminant of interest, CF is contamination factor in Eq. (1). According to Yi et al. (2017), PERI is graded as PERI < 150 (low risk), 151 < PERI < 300 (moderate risk), 301 < PERI 600 (high risk) and PERI > 320 (very high risk).

Human health risk assessments

Direct ingestion and dermal contact have been suggested as possible human exposure pathways to heavy metal contamination in water. The risk of human exposure from drinking surface and underground water sources was assessed using US EPA risk models for carcinogenic and non-carcinogenic evaluation which is based on Eqs. (12) through (15) (Li and Zhang 2010; Naveedullah et al. 2014; US EPA 1989). The chronic daily intake and hazard index parameter [Eq. (9)] was used to assess the health risk associated with heavy metal absorption through the consumption of surface and groundwater in the research area (Wu et al. 2009; Boateng et al. 2015; Muhammad et al. 2011). CR—ingestion and CR—dermal contact was summed up to get the total cancer risk ($\text{Risk}_{\text{total}}$), while the cumulation of HQ—ingestion and HQ—dermal gave hazard index (HI), as shown in Eqs. (16) and (17)

$$\text{CR}-\text{ingestion} = \left(\frac{\text{CS} \times \text{IR}_{\text{W}} \times \text{EF} \times \text{ED} \times \text{TR} \times \text{CSF}}{\text{BW} \times \text{AT}}\right) \tag{12}$$

$$\text{CR}-\text{dermal} = \left(\frac{\text{CS} \times \text{SA} \times \text{EF} \times \text{ED} \times \text{TR} \times \text{CSF}}{\text{BW} \times \text{AT} \times \text{GIABS}}\right) \tag{13}$$

$$\text{HQ}-\text{ingestion} = \left(\frac{\text{CS} \times \text{IR}_{\text{W}} \times \text{EF} \times \text{ED} \times \text{TR}}{\text{BW} \times \text{AT} \times \text{RfD}}\right) \tag{14}$$

$$\text{HQ}-\text{dermal} = \left(\frac{\text{CS} \times \text{SA} \times \text{EF} \times \text{ED} \times \text{TR}}{\text{BW} \times \text{AT} \times \text{GIABS} \times \text{RfD}}\right) \tag{15}$$

where CS = heavy metal concentration in water (mg/L), IRw = daily water ingestion rate (L/day) (2.5L/day–adults and 0.78L/day–children) (Brindha et al. 2016), EF = exposure frequency (350-day year^{-1}) (Asare-Donkor et al. 2016), ED = exposure duration (26 years–adults and

6 years–children) (UNDESA 2013), TR = target risk (1×10^6 kg/mg) (US EPA 2020a, b, 2015), CSF = cancer slope factor, BW = body weight (80 kg for adults and 15 kg for children) (ICMR 2009), AT = averaging time (non-carcinogens = ED × 365 days, carcinogen = 70 × 365 days) (Asare-Donkor et al. 2016), RfD = reference dose, SA = skin surface area (19652cm^2–adults and 6365cm^2–children) (Asare-Donkor et al. 2016). GIABS = fraction of contaminant absorbed in gastrointestinal tracts (unit-less) (1.0 for adults and children) (Naveedullah et al. 2014), RfD and CSF values of some heavy metals are presented in Table 3.

$$\text{Total cancer risk}\left(\text{Risk}_{\text{total}}\right) = \sum \text{CR} - \text{ingestion} + \text{CR} - \text{dermal} \tag{16}$$

$$\text{Hazard Index (HI)} = \sum \text{HQ} - \text{ingestion} + \text{HQ} - \text{dermal} \tag{17}$$

Results and discussion

Quality control and method validation

The equipment used to determine the amounts of heavy metals in the samples (Agilent AA500F) has a high sensitivity—typically > 0.9 absorbance with a precision of < 0.5 percent relative standard deviation (RSD) for a 5 mg/L Cu standard from ten-second integrations. Limits of detection (LOD), limit of quantification (LOQ), repeatability, reproducibility, accuracy, and precision were all used to determine the quality of each water sample. According to the Chinese standard HJ 743–2015, the heavy metal congeners were measured using calibration curves that encompass the dynamic range in which the compounds of interest are expected to be present, and recoveries were extremely good.

Table 3 Reference values for heavy metals due to exposure *Source*: Vetrimurugan et al. (2017)

Heavy metal	Reference dose (RfD in mg/kg/day)	Cancer slope factor (CSF in mg/kg/day)$^{-1}$	References
Ni	0.2	0.91	Kim et al. (2011)
Mn	0.024	No CSF	IRIS from US EPA (2009)
Cr	0.003	No CSF	IRIS from US EPA (2009)
Cd	0.0005	6.3	IRIS from US EPA (2009)
Pb	0.0036	No CSF	Viridor Waste Ltd (2009)
Zn	0.3	No CSF	IRIS from US EPA (2009)
Fe	0.7	No CSF	US EPA, (2011)
Cu	0.005	No CSF	US EPA (2007)

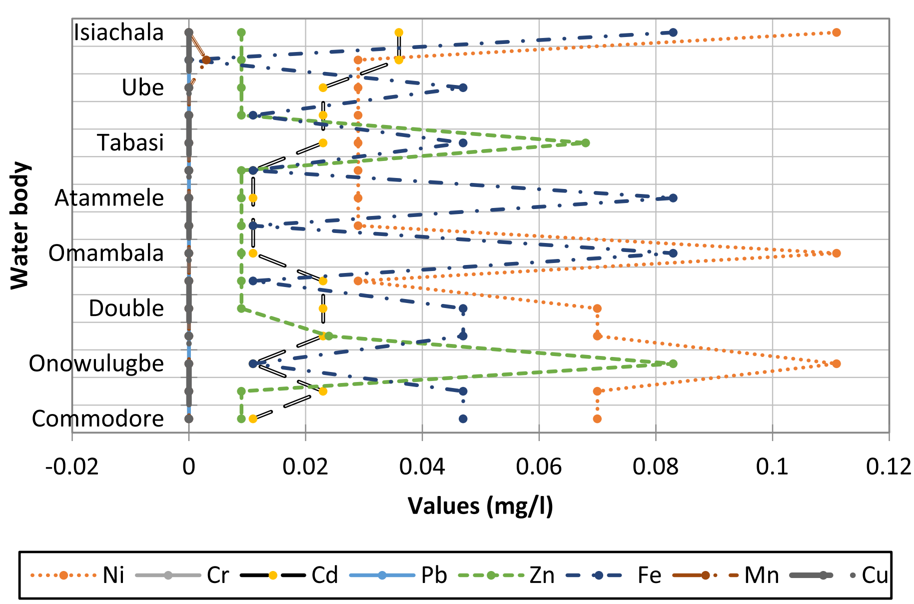

Fig. 4 Semantic differential chart

Table 4 Concentration of Heavy Metals (mg/L) in Water Samples from Ifite Ogwari ($n=15$)

Code	Water body	Ni	Cr	Cd	Pb	Zn	Fe	Mn	Cu
SA	Isiachala	0.111	ND	0.036	ND	0.009	0.083	ND	ND
SB	Iyiutu	0.029	ND	0.036	ND	0.009	ND	0.003	ND
SC	Ube	0.029	ND	0.023	ND	0.009	0.047	ND	ND
SD	Ahala	0.029	ND	0.023	ND	0.009	0.011	ND	ND
SE	Tabasi	0.029	ND	0.023	ND	0.068	0.047	ND	ND
SF	Nabaloku	0.029	ND	0.011	ND	0.009	0.011	ND	ND
SG	Atammele	0.029	ND	0.011	ND	0.009	0.083	ND	ND
SH	Ogbu	0.029	ND	0.011	ND	0.009	0.011	ND	ND
RA	Omambala	0.111	ND	0.011	ND	0.009	0.083	ND	ND
WA	Igbazine	0.029	ND	0.023	ND	0.009	0.011	ND	ND
WB	Double	0.070	ND	0.023	ND	0.009	0.047	ND	ND
WC	Ogba	0.070	ND	0.023	ND	0.024	0.047	ND	ND
WD	Onowulugbe	0.111	ND	0.011	ND	0.083	0.011	ND	ND
WE	Orator	0.070	ND	0.023	ND	0.009	0.047	ND	ND
WF	Commodore	0.070	ND	0.011	ND	0.009	0.047	ND	ND

Degree of heavy metals contamination in waterbody samples

Figure 4 depicts the semantic differential chart, while Table 4 displays the concentration of heavy metals in water samples from Ifite Ogwari, Anambra State, Nigeria. A detailed examination of the laboratory data reveals that all samples (water bodies) in Ifite Ogwari were free of Cr, Pb and Cu with Ni being the highest in Isiachala, Omambala, and Onowulugbe each having the same concentration of 0.111 mg/L. In 12 sample locations, the concentration of Zn was 0.009 mg/L, while Mn was only found in Iyiutu (0.003 mg/L). Heavy metals are known to be toxic to humans in minute concentrations. The World Health Organization and the United States Environmental Protection Agency provide guideline values for different exposure mediums (oral, dermal, and inhalation) and source pollutants, indicating a propensity to cause adverse health effects (non-cancerous) and cancer-based illnesses for a period of respondents' (adult and children) lifetime (WHO 2017; US EPA 2017). According to the WHO, the tolerable guideline limit for Ni is 0.07 mg/L, indicating that residents of the sample locations (Isiachala, Omambala, and Onowulugbe) may get dermatitis as a result of persistent exposure (WHO 2007). Cd and Zn are known to dissolve with anions (sulfates, chlorides, carbonates), affecting the taste and appearance of water. High concentrations above 0.05 mg/L can cause cytotoxic-induced tumors (cellular mutation) in sensitive organs (kidney and liver) (WHO 2011; 2003). When the human body is poisoned with Cd, Zn is provided as a detoxifying agent to displace and eliminate the Cd through urination or perspiration (Shamelashvili et al. 2020). Furthermore, Fe and Mn are known to affect the color, taste, dissolved oxygen, and turbidity of bodies of water, and microbes use Fe and Mn particulates to make water less palatable and useful for domestic use without the use of a proper treatment or flocculation process (WHO 2011), implying that Fe and Mn have no negative health effects (Xu et al. 2020; Sun et al. 2017).

Multivariate statistical analysis

Correlation analysis of sample locations

The Pearson correlation, shown in Table 5, was conducted for sample locations using the analyzed heavy metal concentration to aggregate the relationship via water body aquifer interactions as Isiachala correlated strongly with Ube, Ahala, Nabaloku, Ogbu, Omambala, Igbazine, Double, Ogba, Orator, and Commodore (0.72–0.99). Iyiutu correlated strongly at 0.86 with Ahala and Igbazine. Nabaloku correlated with Ogbu, Omambala, Igbazine, Double, Ogba, Onowulugbe, Orator, and Commodore, having a range of 0.76–0.99. After assessing a fraction of the correlation across these locations, it is important to note that water is not stationary as it passes through numerous water cycle processes via various environmental strata (atmosphere, hydrosphere, and lithosphere) where there are likely metal releases that are dissipated and concentration levels reduced across multiple water reservoirs.

Factor pattern of sample locations

Principal component analysis was conducted to derive factor patterns across sample location variables using heavy metal concentration levels as revealed in Table 6 and Fig. 5, which produced three factors having a cumulative variance of 33.40%. Factor 1 showed the highest number of locations with aggregates of variance (5.60)

Table 5 Pearson correlation matrices of sample locations

Variables		SA	SB	SC	SD	SE	SF	SG	SH	RA	WA	WB	WC	WD	WE	WF
Isiachala	SA	1														
Iyiutu	SB	0.3	1													
Ube	SC	**0.82**	0.07	1												
Ahala	SD	0.72	**0.86**	0.49	1											
Tabasi	SE	0.12	−0.2	0.31	0.08	1										
Nabaloku	SF	**0.86**	0.58	0.52	**0.89**	0.2	1									
Atammele	SG	0.67	−0.3	**0.92**	0.12	0.35	0.26	1								
Ogbu	SH	**0.86**	0.58	0.52	**0.89**	0.20	**0.99**	0.26	1							
Omambala	RA	**0.98**	0.12	**0.77**	0.59	0.16	**0.83**	0.69	**0.83**	1						
Igbazine	WA	0.72	**0.86**	0.49	**0.99**	0.08	**0.89**	0.12	**0.89**	0.59	1					
Double	WB	**0.99**	0.35	**0.78**	**0.76**	0.14	**0.91**	0.61	**0.91**	**0.97**	**0.76**	1				
Ogba	WC	**0.96**	0.32	**0.74**	**0.76**	0.34	**0.93**	0.58	**0.93**	**0.95**	**0.76**	**0.97**	1			
Onowulugbe	WD	0.42	0.32	0.02	0.53	0.47	**0.76**	−0.1	**0.76**	0.48	0.53	0.49	0.64	1		
Orator	WE	**0.99**	0.35	**0.78**	**0.76**	0.14	**0.91**	0.61	**0.91**	**0.97**	**0.76**	**0.99**	**0.97**	0.49	1	
Commodore	WF	**0.98**	0.21	**0.74**	0.66	0.17	**0.88**	0.63	**0.88**	**0.99**	0.66	**0.98**	**0.97**	0.54	**0.98**	1

Bold: significance ≥ 0.75

Weak correlation ≤ 0.50; moderate correlation = 0.50–0.75; strong correlation ≥ 0.75

Table 6 Factor matrix of sample locations

	*F*1	*F*2	*F*3
Isiachala	**0.967**	0.193	−0.149
Iyiutu	0.449	**−0.800**	−0.267
Ube	**0.742**	0.527	−0.208
Ahala	**0.839**	−0.469	−0.136
Tabasi	0.234	0.259	**0.807**
Nabaloku	**0.955**	−0.260	0.112
Atammele	0.530	**0.819**	−0.098
Ogbu	**0.955**	−0.260	0.112
Omambala	**0.928**	0.293	−0.028
Igbazine	**0.839**	−0.469	−0.136
Double	**0.984**	0.117	−0.100
Ogba	**0.986**	0.098	0.126
Onowulugbe	0.595	−0.376	**0.670**
Orator	**0.984**	0.117	−0.100
Commodore	**0.957**	0.203	−0.004
Eigenvalue	10.29	2.57	1.34
Variability (%)	5.60	18.37	9.43
Cumulative %	5.60	23.97	33.40

Bold: significance ≥ 0.75

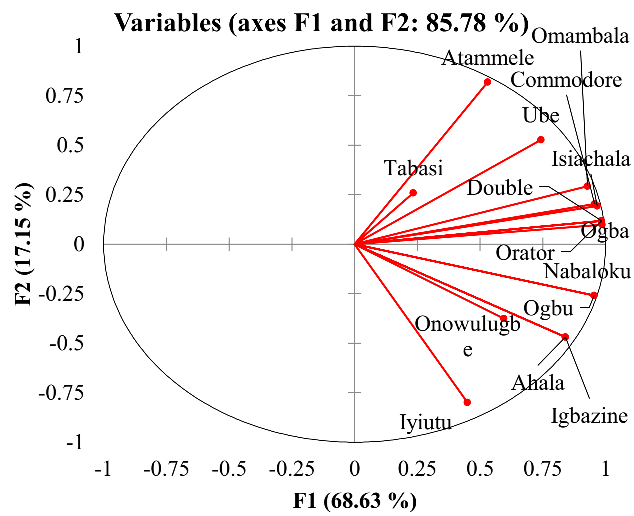

Fig. 5 Variable chart of sample locations

Table 7 Correlation matrices of heavy metals

	Ni	Cd	Zn	Fe	Mn
Ni	1				
Cd	−0.03	1			
Zn	0.24	−0.15	1		
Fe	0.46	−0.02	−0.16	1	
Mn	−0.23	0.51	−0.12	−0.37	1

in Isiachala, Ube, Ahala, Nabaloku, Ogbu, Omambala, Igbazine, Double, Ogba, Orator, and Commodore with a strong variable range of 0.742–0.986. Factor 2 and 3 produced variance levels of 18.37% and 9.43% with Iyiutu

Table 8 Factor matrix of heavy metals

	F1	F2	F3
Ni	**−0.645**	−0.391	−0.505
Cd	0.558	**−0.634**	−0.336
Zn	−0.264	0.501	**−0.770**
Fe	**−0.652**	**−0.633**	0.146
Mn	**0.808**	−0.221	−0.305
Eigenvalue	1.87	1.26	1.07
Variability (%)	46.66	21.88	11.20
Cumulative (%)	46.66	68.54	79.74

Bold: significance ≥ 0.75

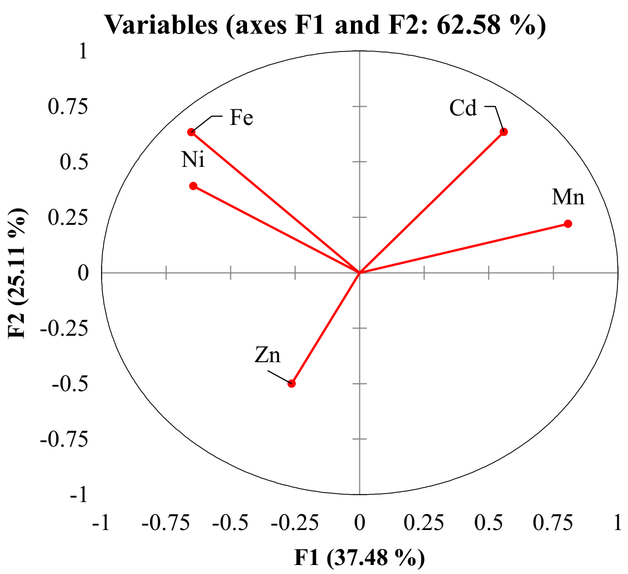

Fig. 6 variable chart of sample locations

and Atammele in Factor 2 and Tabasi and Onowulugbe in Factor 3.

Correlation analysis of heavy metals

Heavy metals (Ni, Cd, Zn, Fe, and Mn) displayed considerable interaction potentials among studied components, according to Pearson correlation (Table 7) (Okechukwu et al. 2021; Barzegar et al. 2019; 2016; 2017). Positive and negative values were found to have medium (0.50–0.70) and weak (≤0.50) correlation matrices, respectively. Natural (rock mineral particulate resuspension) and anthropogenic (industrial emission and releases, automobile, mining, petrochemical) processes are known to interact positively and/or negatively, resulting in a variable increase or decrease in heavy metal concentrations across a variety of environmental mediums (Omokpariola et al. 2020).

Factor pattern of heavy metals

As indicated in Table 8 and Fig. 6, the principal component analysis was extracted using varimax rotation, yielding three factors with a total variance of 79.74%. Factor 1 was responsible for 46.6% in Ni, Fe, and Mn, which could be attributed to anthropogenic rather than natural releases with potentially hazardous concentrations (Utom et al. 2013). In Cd and Fe, factor 2 produced a variation of 21.88%, which can be linked to anthropogenic releases (US EPA 2017). With 11.20% variance, Zn was dominating in Factor 3, indicating that the occurrence might be geogenic and anthropogenic (Bhutiani et al. 2017).

Ecological risk assessment

In Ifite Ogwari, an ecological risk assessment was undertaken to determine the suitability of various water sources for the ecological system. The contamination factor (CF) of various water samples revealed that Ni ranged from 0.41 to 1.59; Cd from 0.00 to 7.67; Zn from 0.00 to 1.66; Fe from 0.00 to 0.28; and Mn from 0.00 to 0.008, with Ni and Cd. CF values ranging from moderate to extremely high levels above the WHO reference standard in some water locations. Cr, Pb, and Cu were not present (no data), and Zn, Fe, and Mn had low CF levels, as reported by Saddique et al. (2018) and Jiao et al. (2015).

For drinking, residential, and industrial applications, the water quality index (WQI) was evaluated (including anthropogenic activities). The computed WQI value ranged from 44.19 to 45.34 and was divided into 3 WQI types: excellent (very fit to drink), good (moderately fit to drink), and poor (unfit to drink) (Brown et al. 1972). The WQI range corresponds to the status level as shown in Table 8 and Fig. 5a, implying that all sample locations are suitable for drinking and household activities such as cooking and bathing, as well as other activities like irrigation. As a result, appropriate water treatment is recommended to raise the WQI level for portable water use in Ifite Ogwari community.

The degree of contamination (Deg-C) and modified degree of contamination (M.Deg-C) are two indicators used to evaluate the effects of ecological pollution because they consider the site's synergistic effect (Vu et al. 2017; Brady

Table 9 Ecological risk indices

Sample	CF								WQI	N	Deg-C	M.Deg-C	PLI	NPI	PERI
Locations	Ni	Cr	Cd	Pb	Zn	Fe	Mn	Cu							
Isiachala	1.59	0.00	7.67	0.00	0.18	0.16	0.00	0.00	44.19	4	9.59	3.02	0.086	2.50	238.89
Iyiutu	0.41	0.00	7.67	0.00	0.18	0.04	0.008	0.00	45.39	5	8.31	2.09	3.14E-05	2.34	232.47
Ube	0.41	0.00	7.67	0.00	1.36	0.16	0.00	0.00	45.01	4	9.60	2.52	0.169	2.06	234.21
Ahala	0.41	0.00	3.67	0.00	0.18	0.04	0.00	0.00	45.33	4	4.30	2.73	0.003	1.71	112.43
Tabasi	0.41	0.00	3.67	0.00	0.18	0.28	0.00	0.00	44.49	4	4.54	2.83	0.019	1.72	113.63
Nabaloku	0.41	0.00	3.67	0.00	0.18	0.04	0.00	0.00	45.34	4	4.30	5.74	0.003	1.71	112.43
Atammele	0.41	0.00	3.67	0.00	0.18	0.28	0.00	0.00	44.69	4	4.54	9.39	0.019	2.23	113.63
Ogbu	0.41	0.00	7.67	0.00	0.18	0.034	0.00	0.00	45.34	4	8.30	9.46	0.005	2.43	232.43
Omambala	1.59	0.00	7.67	0.00	0.18	0.16	0.00	0.00	44.21	4	9.59	24.44	0.086	2.50	238.89
Igbazine	0.41	0.00	7.67	0.00	0.48	0.16	0.00	0.00	45.33	4	8.72	24.05	0.060	2.00	233.33
Double	1.00	0.00	3.67	0.00	1.66	0.04	0.00	0.00	44.77	4	6.36	23.94	0.056	2.33	116.84
Ogba	1.00	0.00	7.67	0.00	0.18	0.16	0.00	0.00	44.64	4	9.00	23.69	0.054	2.02	235.96
Onowulugbe	1.59	0.00	3.67	0.00	0.18	0.16	0.00	0.00	44.21	4	5.59	23.44	0.041	1.38	118.89
Orator	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44.77	1	1.00	92.18	1.00	1.22	5.00
Commodore	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44.77	1	1.00	91.18	1.00	1.00	5.00

et al. 2015). As anthropogenic and natural factors play a vital impact in the level of heavy metal pollution in a given place, modified degree of contamination and degree of contamination are empirical toolkits that measure the level of contamination in a specific sample site (Yan et al. 2016; Duodu et al. 2016). Table 9 and Fig. 7b, c give an adequate classification of the two indices, which shows that M.Deg-C from Isiachala–Tabasi had low contamination, as other locations varied between moderate and high contamination. As regards Deg-C, locations (Isiachala, Iyiutu, Ube, Ogbu, Omambala, Igbazine, Double, Ogba, Onomwulugbe) had a high degree of contamination, as other locations were within low to moderate degrees of contamination.

Other important pollution toolkits used to analyze the effect of heavy metals on the sample sites are the Nemerow pollution index (Yan et al. 2016) and the pollution load index (Ijeh and Onu 2013). Table 8 and Figs. 6a, b show the NPI and PLI indices, with NPI ranging from unpolluted to mildly polluted across all locations, with values ranging from 1.00 to 2.50, and PLI indicating that there was no pollution at all locations. Accordingly, single elemental indices do not provide the same level of insight into synergistic effects as multi-elemental evaluation. As a consequence, the NPI and PLI indices are useful for assessing the combined effects of heavy metals, implying that the water bodies in the Ifite Ogwari community were relatively pollution-free but required additional purification modalities to avoid severe ecological and health impacts to humans, flora, and fauna, respectively.

Another effective method for assessing the likely impact of multi-elemental contamination on the ecology of the Ifite Ogwari community is potential ecological risk indices (PERI). PERI values across all the sample locations are given in Table 9 and Fig. 8c. Using the PERI aggregations (low ecological risk, moderate risk, high ecological risk, and extremely high ecological risk), it is evident that the entire water samples ranged between 5.00 and 238.89, indicating that Ahala, Tabasi, Nabaloku, Atammele, Double, and Onowulugbe were within moderate risk while Isiachala, Iyiutu, Ube, Ogbu, Omambala, and Igbazine were within high risk. Similarly, we can state that immersed anthropogenic activities such as agriculture, mining, construction, and artisanal events have the potential to pose a high ecological risk in the aforementioned locations, even though chemical reactions (dissolution, hydrolysis, redox) can cause an alternating increase and or decrease in heavy metal pollution based on natural phenomena (tidal movement, rock formation, aquifer displacement, chemical mobility, and leaching) in the ecosystem (Tytła 2019; Czaplicka et al. 2017; Xiao et al. 2016, 2015).

Human health risk assessment

Carcinogenic risk assessment

Table 10 and Fig. 9 show the total cancer risk calculated using the cancer slope factor (CSF) from the US

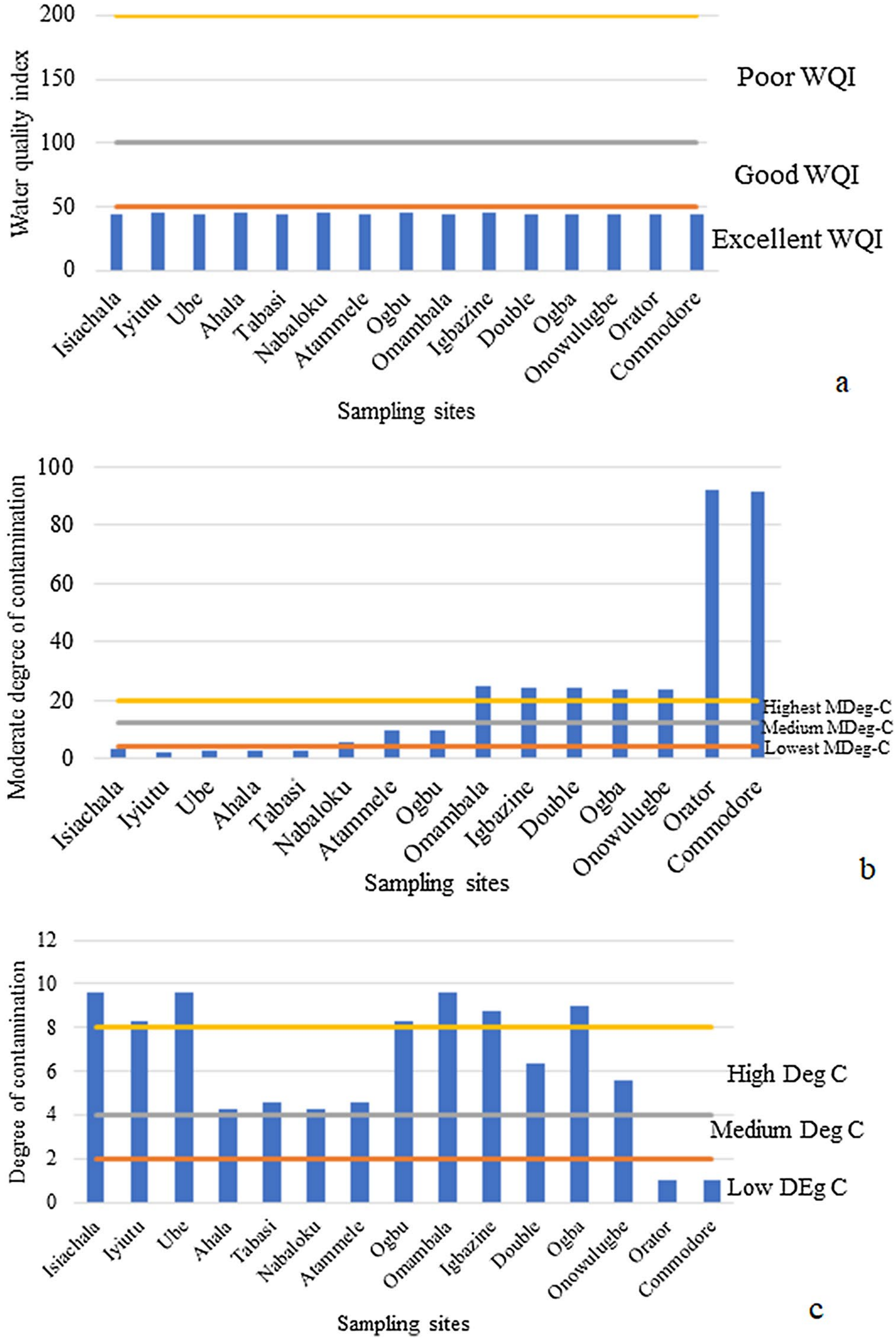

Fig. 7 Multi-elemental indices of heavy metals in water samples, **a** water quality indices (WQI), **b** Modified degree of contamination M.Deg-C and **c** degree of contamination (Deg-C)

Environmental Protection Agency (US EPA) reference guide (mg/kg/day)$^{-1}$. As can be seen, the overall cancer risk for two respondents (adults and children) was calculated using Ni and Cd. Based on the tolerable cancer risk range of 1.0E–06 to 1.0E–04 (US EPA 2020a, b), the total cancer risk of both adults and children was within a safe range with no carcinogenic health impact (Omokpariola and Omokpariola 2021).

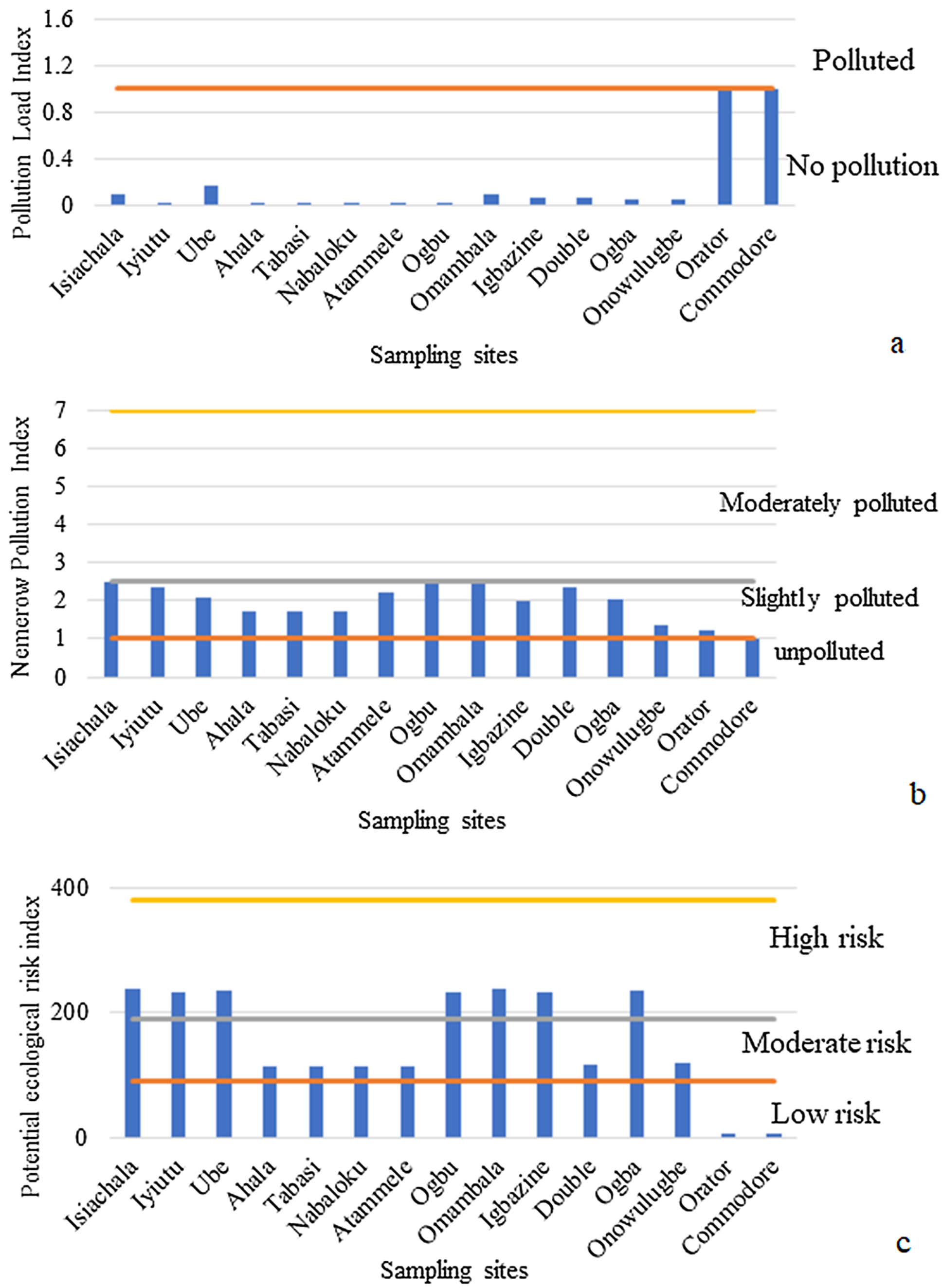

Fig. 8 Multi-elemental indices of heavy metals in water samples, **a** pollution load index (PLI), **b** nemerow pollution index (NPI) and **c** potential ecological risk index (PERI)

Non-carcinogenic

The evaluation of non-cancer risk was analyzed using different exposure media (ingestion and dermal) and a reference dose (RfD). The sum of exposure mediums was used to determine the cumulative hazard quotient (HQ). The HQ for adults and children was below one (1), as shown in Table 11 and Fig. 10. On the basis of the presented results, the water sources from Ifite Ogwari pose no adverse health risk to the residents.

Except for Okafor et al. (2022a), who studied human health risk assessment of polycyclic aromatic

Table 10 Cancer risk evaluation for heavy metals

	Ni	Cd	Zn	Fe	Mn	Total Cancer risk
Adult						
Isiachala	2.04E−05	4.58E−05	No CSF	No CSF	No CSF	6.62E−05
Iyiutu	5.33E−06	4.58E−05	No CSF	No CSF	No CSF	5.11E−05
Ube	5.33E−06	2.93E−05	No CSF	No CSF	No CSF	3.46E−05
Ahala	5.33E−06	2.93E−05	No CSF	No CSF	No CSF	3.46E−05
Tabasi	5.33E−06	2.93E−05	No CSF	No CSF	No CSF	3.46E−05
Nabaloku	5.33E−06	1.40E−05	No CSF	No CSF	No CSF	1.93E−05
Atammele	5.33E−06	1.40E−05	No CSF	No CSF	No CSF	1.93E−05
Ogbu	5.33E−06	1.40E−05	No CSF	No CSF	No CSF	1.93E−05
Omambala	2.04E−05	1.40E−05	No CSF	No CSF	No CSF	3.44E−05
Igbazine	5.33E−06	2.93E−05	No CSF	No CSF	No CSF	3.46E−05
Double	1.29E−05	2.93E−05	No CSF	No CSF	No CSF	4.21E−05
Ogba	1.29E−05	2.93E−05	No CSF	No CSF	No CSF	4.21E−05
Onowulugbe	2.04E−05	1.40E−05	No CSF	No CSF	No CSF	3.44E−05
Orator	1.29E−05	2.93E−05	No CSF	No CSF	No CSF	4.21E−05
Commodore	1.29E−05	1.40E−05	No CSF	No CSF	No CSF	2.69E−05
Children						
Isiachala	3.17E−05	7.12E−05	No CSF	No CSF	No CSF	1.03E−04
Iyiutu	8.28E−06	7.12E−05	No CSF	No CSF	No CSF	7.95E−05
Ube	8.28E−06	4.55E−05	No CSF	No CSF	No CSF	5.38E−05
Ahala	8.28E−06	4.55E−05	No CSF	No CSF	No CSF	5.38E−05
Tabasi	8.28E−06	4.55E−05	No CSF	No CSF	No CSF	5.38E−05
Nabaloku	8.28E−06	2.18E−05	No CSF	No CSF	No CSF	3.00E−05
Atammele	8.28E−06	2.18E−05	No CSF	No CSF	No CSF	3.00E−05
Ogbu	8.28E−06	2.18E−05	No CSF	No CSF	No CSF	3.00E−05
Omambala	3.17E−05	2.18E−05	No CSF	No CSF	No CSF	5.35E−05
Igbazine	8.28E−06	4.55E−05	No CSF	No CSF	No CSF	5.38E−05
Double	2.00E−05	4.55E−05	No CSF	No CSF	No CSF	6.55E−05
Ogba	2.00E−05	4.55E−05	No CSF	No CSF	No CSF	6.55E−05
Onowulugbe	3.17E−05	2.18E−05	No CSF	No CSF	No CSF	5.35E−05
Orator	2.00E−05	4.55E−05	No CSF	No CSF	No CSF	6.55E−05
Commodore	2.00E−05	2.18E−05	No CSF	No CSF	No CSF	4.17E−05

Cancer slope factor (CSF): Ni = 0.91; Cd = 6.3; Zn = Fe = Mn = No CSF

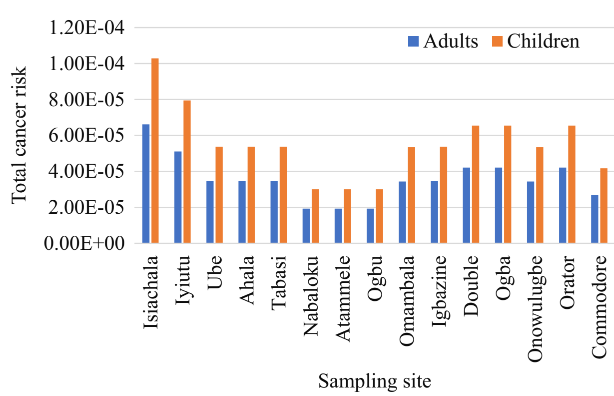

Fig. 9 Total cancer risk of populace across different sampling locations

hydrocarbons (PAHs) in surface and groundwater from Ifite Ogwari and Ihedioha et al. (2021), who evaluated ecological and human health risks of potential toxic metals in paddy soil, rice plants, and rice grains (*Oryza sativa*) in the rice field of Omor, a neighboring community to Ifite Ogwari, this study may be the first of its kind in terms of evaluating the exposure risk to heavy metals through surface and groundwater used for drinking and other household activities in Ifite Ogwari and environs. Exposure to heavy metals via drinking water may expose people in such a community to developing cancer at some point in their lives if the water sources are not monitored periodically.

Table 11 Non-carcinogenic risk evaluation of heavy metals

	Ni	Cd	Zn	Fe	Mn	Hazard index
Adult						
Isiachala	3.92E−03	5.08E−02	2.12E−05	8.38E−05	No Data	5.49E−02
Iyiutu	1.03E−03	5.08E−02	2.12E−05	No Data	8.83E−05	5.20E−02
Ube	1.03E−03	3.25E−02	2.12E−05	4.74E−05	No Data	3.36E−02
Ahala	1.03E−03	3.25E−02	2.12E−05	1.11E−05	No Data	3.36E−02
Tabasi	1.03E−03	3.25E−02	1.60E−04	4.74E−05	No Data	3.37E−02
Nabaloku	1.03E−03	1.56E−02	2.12E−05	1.11E−05	No Data	1.66E−02
Atammele	1.03E−03	1.56E−02	2.12E−05	8.38E−05	No Data	1.67E−02
Ogbu	1.03E−03	1.56E−02	2.12E−05	1.11E−05	No Data	1.66E−02
Omambala	3.92E−03	1.56E−02	2.12E−05	8.38E−05	No Data	1.96E−02
Igbazine	1.03E−03	3.25E−02	2.12E−05	1.11E−05	No Data	3.36E−02
Double	2.47E−03	3.25E−02	2.12E−05	4.74E−05	No Data	3.51E−02
Ogba	2.47E−03	3.25E−02	5.65E−05	4.74E−05	No Data	3.51E−02
Onowulugbe	3.92E−03	1.56E−02	1.96E−04	1.11E−05	No Data	1.97E−02
Orator	2.47E−03	3.25E−02	2.12E−05	4.74E−05	No Data	3.51E−02
Commodore	2.47E−03	1.56E−02	2.12E−05	4.74E−05	No Data	1.81E−02
Children						
Isiachala	5.65E−03	7.32E−02	3.05E−05	1.21E−04	No Data	7.90E−02
Iyiutu	1.48E−03	7.32E−02	3.05E−05	No Data	1.27E−04	7.48E−02
Ube	1.48E−03	4.68E−02	3.05E−05	6.83E−05	No Data	4.84E−02
Ahala	1.48E−03	4.68E−02	3.05E−05	1.60E−05	No Data	4.83E−02
Tabasi	1.48E−03	4.68E−02	2.31E−04	6.83E−05	No Data	4.86E−02
Nabaloku	1.48E−03	2.24E−02	3.05E−05	1.60E−05	No Data	2.39E−02
Atammele	1.48E−03	2.24E−02	3.05E−05	1.21E−04	No Data	2.40E−02
Ogbu	1.48E−03	2.24E−02	3.05E−05	1.60E−05	No Data	2.39E−02
Omambala	5.65E−03	2.24E−02	3.05E−05	1.21E−04	No Data	2.82E−02
Igbazine	1.48E−03	4.68E−02	3.05E−05	1.60E−05	No Data	4.83E−02
Double	3.56E−03	4.68E−02	3.05E−05	6.83E−05	No Data	5.05E−02
Ogba	3.56E−03	4.68E−02	8.14E−05	6.83E−05	No Data	5.05E−02
Onowulugbe	5.65E−03	2.24E−02	2.81E−04	1.60E−05	No Data	2.83E−02
Orator	3.56E−03	4.68E−02	3.05E−05	6.83E−05	No Data	5.05E−02
Commodore	3.56E−03	2.24E−02	3.05E−05	6.83E−05	No Data	2.60E−02

Reference dose: (RfD) = 0.02; Cd = 0.0005; Zn = 0.3; Fe = 0.7; Mn = 0.024

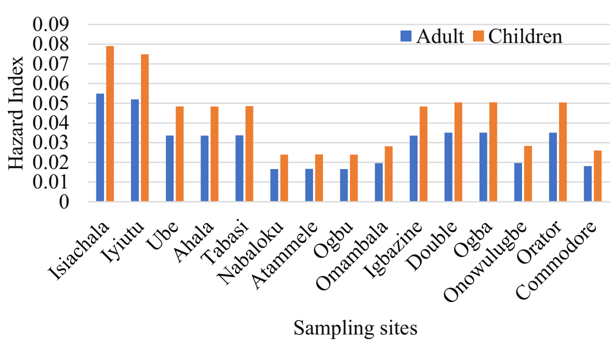

Fig. 10 Hazard index of populace across different sampling locations

Conclusion

The concentrations of Ni, Cr, Cd, Pb, Zn, Fe, Mn, and Cu in water samples obtained from the major water sources in Ifite Ogwari, namely streams, river, and hand-dug wells, were examined. Heavy metal accumulation in water sources can be hazardous to human health and, in some cases, can lead to life-threatening illnesses, including organ cancer. Ecological indices revealed the ecological impact of multi-element matrices, while health risk assessments revealed that there was no adverse cancer risk or non-cancer risk across respondents (adults and children). The results revealed that anthropogenic discharge has a significant mobility impact on the natural level of metals in Ifite Ogwari water, necessitating effective treatment. The study's findings, which may be used in other places with similar environmental conditions, can serve as a useful benchmark for both local and national governments in developing appropriate approaches to managing surface and groundwater resources.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest No potential conflict of interest was reported by the authors.

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