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Potential Health Implications of Heavy Metal Contamination of Streams Near Quarry Sites in Akamkpa, Cross River State, Nigeria

Zagrożenia zdrowotne spowodowane skażeniem cieków wodnych metalami ciężkimi w rejonie kamieniołomów w Akamkpa, w stanie Cross River w Nigerii

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Abstract: This study examined the potential health implications of heavy metal contamination of streams near quarry sites in Akamkpa, Cross River State. Three rural communities were selected (Awi, Nsan, Old Netim) and three streams near operating quarries were sampled. 216 water samples were analysed for 15 parameters (temperature, pH, colour, turbidity, TSS, TDS, EC, Total hardness, DO, BOD, COD, CI, NO_S, SO_4, HCO_3^-), 7 heavy metals (Pb, Cu, Cr, Zn, Cd, Ni, Ba) and 2 microbiological parameters (Total Coliform, E-Coli). Samples were collected between April 2023 and June 2024, during 2 wet and 2 dry seasons. Atomic Absorption Spectrophotometer (AAS) was used for testing heavy metals. Results from the laboratory analyses were tested for differentials using ANOVA. Nemerow Pollution Index was applied to assess the overall pollution status of these streams. The potential health burden was determined using Hazard Index (HI) and Risk Index (RI) models. Results showed that RI for children was greater than 10^{-6} threshold value in stream 1 and 3. HI values for children and adults were insignificant. Stream 1 had heavy metal values that were significantly higher than stream 2 and 3 for all parameters. Zn posed a significantly higher health risk in stream 1 than in stream 2 and 3. Cd in stream 3 was above permissible limits. Stream 3 was the most polluted posing carcinogenic health risk due to Cd exposure, while water from stream 2 was not polluted and suitable for drinking. Regular monitoring for stream 1 and 3 is advised as the Zn and Cd levels in the two streams exceeded permissible limits. Other streams near quarries in these communities should be examined for possible health risks.

Keywords: health implications, heavy metals, physico-chemistry, contamination, quarry sites, streams, SDG 6: Clean Water and Sanitation, SDG 3: Good Health and Well-being

Streszczenie: W niniejszym artykule zbadano potencjalne skutki zdrowotne skażenia metalami ciężkimi strumieni w pobliżu kamieniołomów w Akamkpa, Cross River State. Wybrano trzy społeczności wiejskie (Awi, Nsan, Old Netim) i pobrano próbki z trzech strumieni w pobliżu czynnych kamieniołomów. Przeanalizowano 216 próbek wody pod kątem 15 parametrów (temperatura, pH, barwa, mętność, TSS, TDS, EC, twardość całkowita, DO, BZT, COD, CI, NOS, SO4, HCO3-), 7 metali ciężkich (Pb, Cu, Cr, Zn, Cd, Ni, Ba) i 2 parametrów mikrobiologicznych (całkowita liczba bakterii coli, E-Coli). Pobieranie próbek przeprowadzono w okresie od kwietnia 2023 r. do czerwca 2024 r. w ciągu 2 pór deszczowych i 2 pór suchych. Do badania metali ciężkich użyto absorpcyjnej spektrofotometrii atomowej (Atomic Absorption Spectrophotometer – AAS). Wyniki analiz laboratoryjnych oceniono pod kątem zmiennych przy użyciu analizy wariancji (ANOVA). W celu oceny ogólnego poziomu zanieczyszczenia wybranych cieków wodnych zastosowano wskaźnik zanieczyszczenia Nemerowa (Nemerov Pollution index). Potencjalne zagrożenia dla zdrowia określono przy użyciu modeli wskaźnika zagrożenia (Hazard Index – HI) i wskaźnika ryzyka (Risk Index – RI). Wyniki wykazały, że wskaźnik RI dla dzieci przekroczył wartość progową 10^{-6} w strumieniu 1 i 3. Wartości wskaźnika HI dla dzieci i dorosłych były nieznaczne. Zawartość metali ciężkich w Strumieniu 1 znacznie przewyższała wartości dla strumieni 2 i 3 w zakresie wszystkich parametrów. Zawartość Zn w strumieniu 1 stanowiła znacznie większe zagrożenie dla zdrowia w strumieniu 1 niż w strumieniach 2 i 3. Zawartość Cd w strumieniu 3 przekraczała dopuszczalne wartości. Strumień 3 był najbardziej zanieczyszczony substancjami kancerogennymi w postaci dużej zawartości Cd, podczas gdy strumień 2 nie był zanieczyszczony i woda z niego nadawała się do spożycia. Zaleca się regularne monitorowanie strumieni 1 i 3 ze względu na wyższe od dozwolonych zawartości Zn i Cd w obu strumieniach. Należy objąć badaniami inne cieki wodne znajdujące się w pobliżu kamieniołomów pod kątem możliwych zagrożeń zdrowotnych.

Słowa kluczowe: wpływ na zdrowie, metale ciężkie, chemia fizyczna, zanieczyszczenia, kamieniołomy, cieki wodne, SDG 6: Czysta woda i warunki sanitarne, SDG 3: Dobre zdrowie i jakość życia

Introduction

Potential health implications or burden refers to the likelihood of developing chronic diseases as a result of certain risk factors and the impact they may have on an individual's health and quality of life. It is the estimated possible impacts of a health problem on a given population, or community. It could also be seen as a possible impact of a particular risk factor on individuals or society. It may be associated with a health issue that has not yet occurred or with a condition currently not considered serious or deadly but having the potential to cause significant harm in the future (ATSDR, 2022). For example, exposure to environmental toxins or unhealthy lifestyle habits may not cause immediate health problems, but it can lead to chronic diseases such as heart disease, cancer or respiratory diseases in the long term. The disease burden through water results from water-associated communicable and non-communicable diseases and is influenced by water pollution with chemicals, solid waste (Eze et al. 2025), pathogens, insects and other disease vectors. Pressures in the environment result in changes in the state of the water body, chemical pollution, microbiological contamination and the presence of vectors.

Elevated levels of heavy metals in water and crops near quarry sites have been repeatedly documented across various Nigerian regions with concentrations exceeding WHO limits (Ganiya et al. 2023; Okafor and Njoku 2024). Beyond this, reviewed studies have identified significant heavy metal pollution associated with quarry sites globally and, with epidemiological evidence linking this pollution to health risks such as intoxication and potential carcinogenic effects (Fattah et al. 2021; Scimeca et al. 2024). However, Bisong (2024) maintained that most of these environmental problems can be tackled if the main cause (the mind) is tackled

1. Problematics

Natural resources used in making traditional hard flooring such as granite, limestone, marble, sandstone, slate, and even clay to make ceramics are obtained through quarrying. However, like many other anthropogenic activities, quarrying has a significant impact on the environment. According to Safe Drinking Water Foundation (SDWF 2017), heavy metal pollution is caused when such metals as arsenic, cobalt, copper, cadmium, lead, silver and zinc contained in excavated rock or exposed in an underground mine come in contact with water.

This study concentrated on Akamkpa in Cross River State as a case study due to the proliferation of quarries in some rural communities, with lack of attendance of water facilities in the areas hosting the quarries. Available records show that in 2010, there were 24 quarries in Akamkpa Local Government Area of Cross River State (Ekwok 2010), but based on our recognizance survey, there are presently 36 quarries in the study area. Akamkpa Local Government Area is made up of rural communities that host these 36 quarries involved in granite and limestone mining due to the abundant mineral/rock deposits in the area. With the proliferation of quarry companies and corresponding increase in production, water pollution may become intense. More worrisome is that the communities hosting these quarries depend on streams for drinking water as the area is intensely fractured, making borehole drilling impossible as posited by Theophilus and Avwenaga (2013). The study area is part of the Precambrian Oban Massif, which is overlaid by cretaceous-tertiary sediments of Calabar Flank. The metamorphic rock units in this area are phyllites, schists, gneisses, and amphibolites. These rocks are intruded by pegmatites, granites, granodiorites, diorites, tonalities, monzonites and dolerites. The geology of this area has made quarrying a major socio-economic activity, which poses a threat to the nearby streams.

There are several adverse health incident reports across Akamkpa urban, Awi and Old Netim showing remarkable consistent community concerns and complaints about the proliferation of quarry sites, lack of potable water supply and water borne diseases within these communities. Several studies have also highlighted adverse health incidents across these communities (Akpan and Ejezie 2003; Ibanga and Eyo 2001; Imoke et al. 2023; Cross River Ministry of Health 2021; Nigeria Center for Disease Control 2023). In 2021, the Cross River State Ministry of Education declared Old Netim and Awi as high-risk areas for diarrhoea and cholera. These three communities have been notable for outbreaks of water-related diseases.

It is on the basis of the above health incident reports as well as the proliferation of quarries, that this study attempts to establish the potential health burden due to possible heavy metal contamination of streams around these quarry sites, as no such study has been done in these three communities. Therefore, this study:

1. Determined the overall pollution status of the streams and
2. Determined the health burden associated with heavy metal pollution using carcinogenic risk assessment approach.

A hypothesis, which states that there is no significant health implication/burden associated with heavy metal contamination as occasioned by the quarrying activities, was formulated and ultimately tested.

2. Study Area

Location: The study area cuts across three communities namely, Awi, Nsan and Old Netim, in Akamkpa Local Government Area (LGA), in the Southern Senatorial district of Cross River State (Fig. 1). The LGA has a landmass of 4,300 square kilometres, and lies within longitudes $8^{\circ}20^{1}0$”E and $8^{\circ}23^{1}26$ E and latitudes $5^{\circ}15^{1}0$”N and $5^{\circ}18^{1}26.6$”N. It is bounded to the south by Odukpani and Akpabuyo local government areas, in the northwest by Biase and Yakur local government areas, in the north by Ikom and Etung Local Government areas and the Republic of Cameroon to the West. The three streams studied are Plywood Stream, around the 2 Brothers Quarry, Erokud Stream near the Faith Plant Quarry and Ayiponyore stream, near the Berger Quarry Respectively (Table A1)[1].

Climate: The area falls within the tropical rainforest belt of Nigeria, and is characterized by double maxima rainfall, which lasts from April to October, reaching its

1 All tables are accessible in the Appendix at the end of the article.

climax in the months of June and September. The area experiences convectional rainfall with an annual average rainfall of about 2500 to 3000mm (NIMET 2008). The temperature ranges from 19°C to 23°C during the wet season and between 24°C and 27°C in the dry season. The relative humidity is between 80% and 100%, while vapour in the air averages 29 millibars throughout the year.

Population: The Population census of 2006 established the population of Akamkpa Local Government Area at 151,125 with the figure of 79,440 for men and 71,682 for women (N.P.C. 2006). Most of the quarry staff are indigenes of the community. Social infrastructures include nursery, primary, secondary schools as well as health centres. There are two main ethnic groups in the Local Government Area, the Ejagham and Dusauga IyongIyong people who speak Ejagham and IyongIyong languages. English and Efik languages are widely used for commercial and social interactions. The local government area is made up of 260 villages grouped under 30 clans for political and administrative convenience.

Health Facilities: Akamkpa has a general hospital located at Akamkpa town; others include community health centres, primary health centres as well as private clinics, which are spread across most communities in Akamkpa local government area. Most of the quarry companies run private clinics. However, severe cases are often referred to teaching hospital or clinics in Calabar.

3. Materials and Methods

3.1. Population of the three communities where the streams are located

Awi, Nsan and Old Netim communities are the target population from which data is drawn for the study. Based on the World Bank population growth rate of 2.8%, the total population of the 3 communities as projected to 2022 is 23,120 persons as shown in Table A2.

3.2. Sampling Size and Sampling Technique

Three (3) Streams were purposively selected for sampling within the 3 rural communities where functional quarries are located. The communities are, Awi, Old Netim, and Nsan. Samples were taken from streams that serve as sources of drinking water across the three communities. Samples were taken from the upstream and downstream sections of each stream, with reference to quarry sites. Sample collection was done for four (4) seasons, (2 wet and 2 dry seasons). The first wet season sampling was done between April and June, 2023, while the first dry season sampling was carried out between November and December, 2023. The second dry season sampling was done between February and March, 2024, while the second wet season sampling was done between April and June, 2024 respectively. Water samples were taken from six sampling points (5 meters apart), three downstream (DST) and three upstream (UPST) within each stream (6 samples from each stream). A total of 18 samples were obtained per set of sampling (6 samples x 3 streams), hence with a total of three sets per season, for four seasons, a grand total of 216 samples (18x3x4=216).

3.3. Water Sampling

The sample collection was done by dipping each sample bottle at approximately 20cm below the surface, projecting the mouth of the container against the direction of flow of the stream water (Asishana and Anegbe 2020). The samples were collected using sterilized plastic containers and preserved in 4°C ice chest box before being taken to the laboratory for analysis. A handheld GPS was used to pick the coordinates for mapping of the sampling points.

3.4. Statistical Analysis of Data

Data were analysed using descriptive and inferential statistical methods. The descriptive statistics used include tables and summary statistics. The inferential statistics used include paired sample t-test and analysis

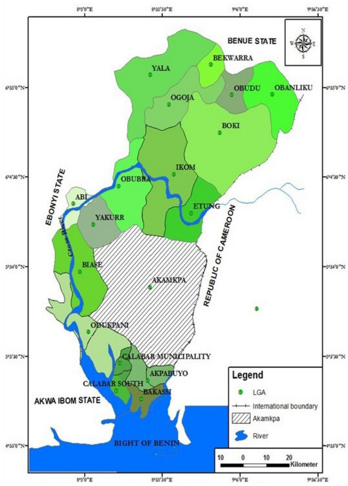

Figure 1. Administrative map of Akamkpa Local Government Area in Cross River State, Nigeria
Source: Ministry of Lands, Cross River State, Nigeria

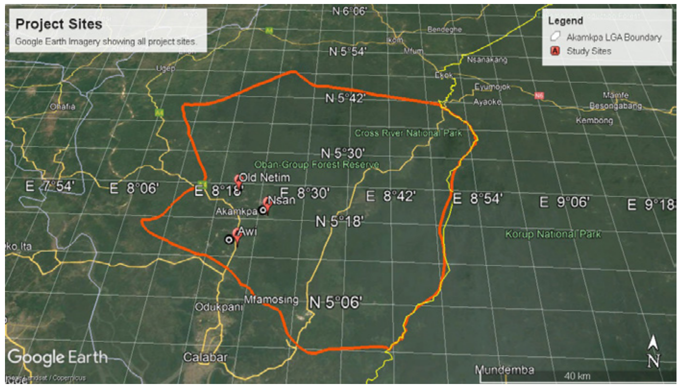

Figure 2. Study Area showing communities where streams are located
Source: Google Earth Imagery, 2024

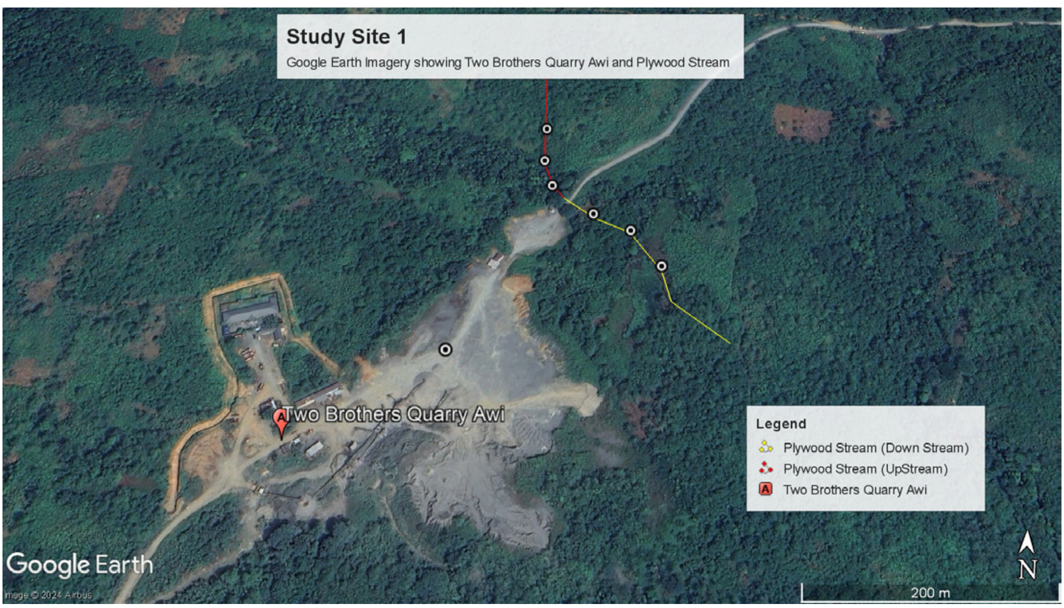

Figure 3. Study location, showing sampling points for stream 1
Source: Google Earth Imagery, 2024

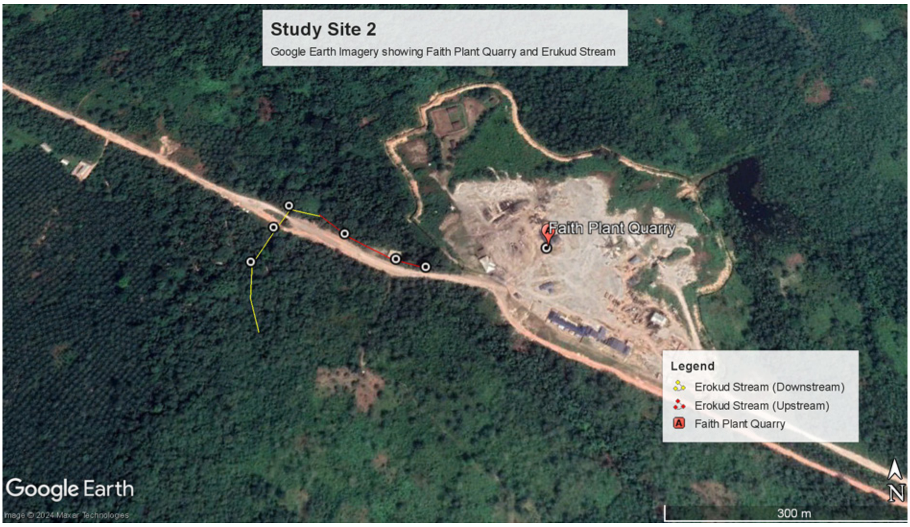

Figure 4. Study location, showing sampling points for stream 2
Source: Google Earth Imagery, 2024

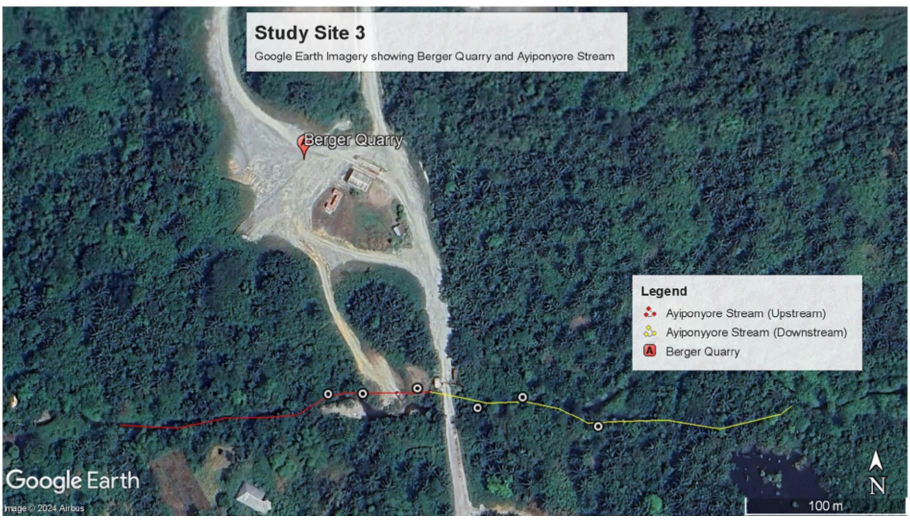

Figure 5. Study location, showing sampling points for stream 3
Source: Google Earth Imagery, 2024

of variance (ANOVA). Statistical Package for Social Sciences (SPSS) was used for statistical data analysis.

3.5. Methods for achieving the objectives

To determine the overall pollution status of the streams, the Nemerow's pollution index (NPI) was used. The calculation method of the comprehensive pollution index is as follows:

$$P_{N=} \frac{\sqrt{(P1)^2 + Pimax^2}}{2}$$

$$P_{1=} \frac{1}{n} \sum \frac{n}{1} = 1$$

Where,

PN = Comprehensive pollution index of sampling point.

Pi max = the maximum value of the single-item pollution index of the pollutants at the sampling point.

Pi = the average value of the single factor index.

Nemerow grading standard is presented in Table A3.

The USEPA model for carcinogenic risk assessment was used to ascertain the health risk associated with ingestion of the metal elements in the sampled streams. The United States Environmental Protection Agency (USEPA 2017) uses risk assessment to characterize the nature and magnitude of health risks to humans and ecological reactors from chemical contaminants and other stressors that may be present in the environment.

The equation is given as:

$$CD1 = \frac{(CXIR\ X\ EF\ X\ ED}{(BW\ X\ AT)} ------------------ (1)$$

$$HQ = \frac{CD1}{RFD} ---------------------- (2)$$

$$LCR = CD1\ X\ SF ------------------(3)$$

$$SF = \text{Slope factor } (\frac{mg}{kg} - \text{Day})^{1}$$

CDI	=	Chronic daily intake (mg/Kg-Day)
CWD	=	Mean concentration of metal in water (mg/L)
IR	=	Water ingestion rate 1.996 L/Day
EF	=	Exposure duration(years)
BW	=	Body weight
AT	=	Average time
HQ	=	Hazard quotient
RFD	=	Chronic reference dose of trace element
LCR	=	Life Time Cancer Risk
SF	=	Slope Factor $(Mg/kg\text{-}day)^{-1}$

Data generated was subjected to one-way ANOVA to compare mean values across the three streams for the computed parameters.

4. Results

4.1. Determination of the overall pollution status of the streams using Nemerow Pollution Index

The pollution assessment for four seasons across the three streams is presented in Tables 4 to 7. Table A4 shows the first wet season pollution assessment for streams 1, 2 and 3. Streams 1 and 2 were not polluted, as reflected in the calculated PN values of 0.07, 0.04 for upstream and downstream of stream 1, as well as 0.29, 0.19 for upstream and downstream of stream 2. Stream 3 had PN values of 6.9 for downstream and 0.44 upstream for the first wet season. This shows that stream 3 (Ayiponyore stream, Old Netim, near Berger quarry) was seriously polluted downstream in the evaluation period.

The second wet season pollution assessment in Table A5 showed that stream 1 had PN values of 0.02, 0.06 for upstream and downstream respectively, signifying no pollution. Stream 2 had PN values of 0.01, 0.05 for upstream and downstream, while stream 3 had PN values of 0.02, 0.01 for upstream and downstream, showing no pollution as well.

Table A6 shows the first dry season pollution assessment. Stream 1 had PN values of 0.61 upstream which shows slight pollution and 1.67 downstream indicative of moderate pollution. Stream 2 had PN values of 0.31 and 0.01 for upstream and downstream, which means there was no pollution at the time of evaluation. Stream 3 also had no pollution at the time of evaluation with PN values of 0.01 and 0.004 for upstream and downstream respectively.

Table A7 shows the second dry season assessment. Stream 1 had PN values of 0.64 and 2.39, signifying slightly polluted downstream and moderately polluted upstream. Stream 2 had PN values of 0.43, 0.40 upstream and downstream, while stream 3 had PN values of 0.48, 0.40 upstream and downstream, respectively, showing no pollution.

To summarize, stream 2 had no pollution, stream 3 was the worst polluted, while stream 1 was slightly polluted, based on NPI pollution assessment.

4.2. Determination of the health implications or burden associated with heavy metal pollution using carcinogenic risk assessment approach

The results of health risk assessment of heavy metals in the streams are reported in Table A8 through 10. CD1, HQ, and LCR for both exposed adults and children's populations in the communities were computed and reported in Table A10. There was no health burden with respect to Ba for the three streams for all computed health risk. Pb and Cr were absent in stream 2 but were present in streams 1 and 3. Pb CDI, HQ, and LCR for adults in stream 1 were $7.4x10^{-6}$, $2.11x10^{-3}$, and $6.29x10^{-8}$ respectively. Stream 3 had $8.22x10^{-7}$, $2.35x10^{-4}$, $6.98x10^{-9}$ respectively for adult. For children, it was $1.73x10^{-5}$, $4.94x10^{-3}$, $1.47x10^{-7}$ in stream 1 and $1.92x10^{-6}$, $5.49x10^{-4}$,$1.63x10^{-8}$ in stream 3. For Cr, values in stream 1 for CDI, HQ, LCR were $3.01x10^{-6}$, $1.003x10^{-2}$, $1.234x10^{-7}$, for adult, and $7.03x10^{-6}$, $2.34x10^{-2}$, $2.88x10^{-7}$ for children respectively. Stream 3, had $7.2x10^{-7}$, $2.4x10^{-3}$, and $2.88x10^{-8}$ for adult; $1.68x10^{-6}$, $5.6x10^{-3}$, and $6.89x10^{-8}$ for children. Cd in stream 1 had $1.2x10^{-5}$, $2.4x10^{-2}$, $7.32x10^{-8}$ for adult; $2.8x10^{-5}$, $9.3x10^{-2}$, $1.71x10^{-7}$ for children respectively. Stream 2 recorded $5.48x10^{-6}$, $1.096x10^{-2}$, $3.34x10^{-8}$, for adult, and $1.29x10^{-5}$, $2.58x10^{-2}$, $7.87x10^{-8}$ for children; stream 3 had $1.03x10^{-4}$, $2.06x10^{-1}$,$6.3x10^{-7}$, for adult, and $2.39x10^{-4}$, $4.78x10^{-1}$, $1.46x10^{-6}$ for children. For Ni, stream 1 had $3.3x10^{-4}$, $1.65x10^{-2}$, and $2.77x10^{-7}$ for adult, and $7.7x10^{-4}$, $3.85x10^{-2}$, and $6.47x10^{-7}$ for children. Stream 2 recorded $1.12x10^{-4}$, $5.6x10^{-3}$, and $9.41x10^{-8}$ for adult, and $2.6x10^{-4}$,$1.3x10^{-2}$, and $2.18x10^{-7}$ for children. Stream 3 had $1.26x10^{-4}$, $6.3x10^{-3}$, and $1.06x10^{-7}$ for adults $2.95x10^{-4}$, $1.48x10^{-2}$, and $2.48x10^{-7}$ for children. For Zn and Cu, LCR was not computed because their cancer slope factor was not established. However, the CDI and HQ for both were computed for the streams. Cu for stream 1 recorded $4.7x10^{-4}$, $1.18x10^{-2}$ for adults, and $1.11x10^{-3}$, $2.78x10^{-2}$ for children for CDI and HQ respectively. Stream 2 were $2.6x10^{-4}$, $6.5x10^{-3}$, for adults, and $5.95x10^{-4}$, $1.49x10^{-2}$ for children. Stream 3 had $1.28x10^{-4}$ and $3.2x10^{-3}$ for adults, and $2.98x10^{-4}$, $7.45x10^{-3}$ for children. Ni had similar values to Cu for the three streams.

Table A9 shows the Hazard Index (HI) for children and adults across the three streams. The HI for children in streams 1, 2 and 3 are $2.0795 \text{ x } 10^{-1}$, $5.91 \text{ x } 10^{-1}$ and $5.11639 \text{ x } 10^{-1}$ respectively. The HI for adults recorded for the three streams was $2.8911 \text{ x } 10^{-1}$, $2.536 \text{ x } 10^{-2}$ and $2.20385 \text{ x } 10^{-1}$ respectively. These are all within the threshold value of 1.0 for non-carcinogenic risk.

Table A10 shows risk index for children and adults across the three streams. Stream 1 had risk index of $1.253 \text{ x } 10^{-6}$ for children while stream 3 had $1.7932 \text{ x } 10^{-6}$ which is greater than the threshold value of 10^{-6}. This means that streams 1 and 2 had carcinogenic health burden for children who drink from the two streams.

Table A8 shows a test of the hypothesis for health risk analysis for heavy metals across streams. Results showed CDI, HQ, and LCR for both adults and children who may be exposed to the water. For all heavy metals, the health risk was not significantly different across streams except for Zn, in which stream 1 had a significantly higher risk than streams 2 and 3.

5. Discussion of Findings

5.1. Determining the overall pollution status of the streams using the Nemerow Pollution Index

The NPI method was used to assess the pollution level of the three streams for four seasons. Tokatli et al. (2023) used the NPI to evaluate the water quality of 10 ponds. Index values of 0.26-1.82 were recorded for 2 ponds. The other 8 ponds had insignificant PN values. Results for the first wet season of pollution assessment recorded PN values of 6.91 downstream of stream 3 (seriously polluted), while streams 2 and 1 had no pollution. The second wet season recorded no pollution across all the streams with PN values of 0.02, 0.06, for stream 1, 0.01, 0.05 for stream 2 and 0.02, 0.01 for stream 3. The low PN values recorded across the second wet season could be attributed to the suspension of quarrying activities during the second wet season, due to community fight against kidnapping in the study area. The first dry season pollution assessment had stream 1 slightly polluted upstream with 0.61 PN value and moderately polluted downstream with PN value of 1.67. The PN values of 0.31, 0.10 for stream 2, and 0.01, 0.004 for stream 3 showed no pollution. The second dry season recorded 0.64 and 2.39 for up and downstream values for stream one, showing slight and moderate pollution. Stream 2 and 3 had low PN values of 0.31, 0.01, 0.011 and 0.004 respectively for the second dry season which aligns with Majumdar & Avishek (2024) non-monsoon (dry season) values of 0.10 and 1.74.

From pollution assessment, stream 2 had the best water quality, with no record of pollution, which made it fit for drinking and domestic use. Su et al. (2022) recorded the same trend within 3 years of evaluating different rivers, with values at 0.22 and 0.34, using the Nemerow pollution index. Wang et al. also reported low PN values of heavy metals which did not reach the threshold. Stream 3 recorded the highest PN value downstream and was most polluted among the three streams. The high pollution index in stream 3 is not unconnected with the quarry activities near the stream, which supports the findings of Cheng et al. (2022). Nemerow pollution index has been successfully applied to evaluate water quality by several researchers (Liu & Cheng 2016; Zhang et al. 2018; Liu 2020; Lalik & Dabrouska 2024).

5.2. Determining the health burden associated with heavy metal pollution using the Carcinogenic Risk Assessment Approach

The findings of this study are consistent with previous studies that have reported elevated levels of heavy metal contaminants in surface water and associated health risks.

The health risk analysis is presented in Table A8. CDI for all heavy metals in all streams evaluated were all below the recommended oral referenced dose both for children and adult. Onyele and Anyanwu (2018), however, reported CDI values of cadmium for adults and children above oral reference dose (RfD) (0.0005mg/kg/day). Ayantobo et al. (2014), Ekere et al. (2014), and Maigari et al. (2016) recorded similar higher cadmium CDI values. Thus, cadmium poses health risk for those exposed to drinking water from the spring. At high concentrations, cadmium affects the liver, placenta, kidneys, lungs, brain, and bones. Experimental data in humans and animals showed that cadmium may cause cancer in humans. Cadmium is also known to be carcinogenic, and it is classified as a group 1 carcinogen by the International Agency for Research on cancer (IARC). Cadmium disrupts the DNA repair system and stimulates proto-oncogenes while inhibiting tumour-suppressor genes (Johns et al. 2023). The present study, however, reported lower Cd, slightly below the oral-referenced dose.

HQ for all heavy metals were all below 1 for all streams. LCRs were all within the acceptable range. Onyele and Anyanwu (2018) reported higher concentrations of heavy metals above oral-referenced dose. Olutona (2023) reported that the health risk assessment of heavy metals in the bed sediments of the evaluated stream revealed that carcinogenic risk was almost insignificant while the non-carcinogenic risk was significant since their values were above the recommended minimal risk level. The results also revealed that children are more vulnerable to hazards than adults. The chronic hazard quotient index for exposure to these metals through ingestion exceeded the acceptable USEPA value of 1.0.

A study by Ustaoglu (2021) reported a total Hazard Index (HI) value of 2.48 for children due to heavy metal exposure through water ingestion which is higher than the HI value of 2.0795 x 10^{-1} reported in this study. This suggested children's health is at a higher risk than adults'.

Conclusion

The three streams evaluated showed values of physico-chemistry parameters below the safe limit. Heavy metals were also below the safe limit except for Cd in stream 3, which was slightly above the safe limit. Coliform had the highest mean value in stream 1, above the NPI limit. Seasonal variation was observed across streams. Which was due to dilution of the streams by rainwater, which may have been impacted by water volume. The Nemerow Pollution Index (NPI) method used to assess the pollution status of the three streams as regards its suitability for drinking was successfully applied. The results showed that the applied method is correct and reasonable. The concentration of NO_3 is within the permissible limit for drinking. The NPI values for pH, are within the allowable limits for drinking and irrigation purposes. In the assessment of water quality, most of the pollutants' concentration did not exceed the NIS/SON standards. There is, however, a need for regular monitoring of water quality, and an adequate plan for environmental management must be implemented to prevent water pollution in the streams. The health risk was of concern due to the results recorded. From the results, the quarry sites tend to have significantly affected the pollution status of streams 1 and 3 in Akamkpa Local Government Area of Cross River State. The findings of this study have important implications for public health policy and practice. The elevated health risks associated with exposure to contaminated streams (drinking water sources) highlight the need for effective mitigation strategies, such as community engagement and education on the long-term health effects of drinking contaminated water.

Recommendations

The following recommendations were made based on the result of the findings:

- Regulatory agencies should increase surveillance around the streams to prevent future risks.
- Other streams should be evaluated to ascertain their quality.
- Residents of the area should be alerted on the slightly elevated concentration of Cd in stream 3 and coliform in stream 1.
- There is a need to ensure that the quarry activities are regulated to avoid contamination of the streams.

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References

Agency for Toxic Substance and Disease Registry. USA ATSDR's 2022. "Substance priority list 2022." https://www.atsdr.cdcgov/spi/index.htm/#2022spi.

Akpan, Samuel S., Gabriel C. Ejezie. 2003. "The Prevalence of Filariasis in Awi, Akamkpa Local Government Area of Cross River State, Nigeria." *Mary Slessor Journal of Medicine* 3(1): 75-80. https://doi.org/10.4314/msjm.v3i1.11002.

Arong, Theophilus A., and Avwenagha Oghenero E. 2013. "Evaluation of Ground Water Resource in Akamkpa Area, Cross River State, Nigeria." *Pelagia Research Library advancesi in Applied Science Research* 4(5): 10-24. https://www.primescholars.com/articles/evaluation-of-ground-water-resource-in-akamkpa-area-cross-river-statenigeria.pdf.

Ayantobo, Olusola, Awomeso Awonusi, Grace Oluwasanya, Saheed Babatunde, and Matthew Taiwo Adewale. 2014. "Non-Cancer Human Health Risk Assessment from Exposure to Heavy Metals in Surface and Ground Water in Igun Ijesha, Southwestern Nigeria." *American Journal of Environmental Sciences* 10(3): 301-311. https://doi.org/10.3844/ajessp.2014.301.311.

Bisong, Peter. 2024. "Tackling Environmental Problems from the Root: An Ibuanyidanda Perspective." *Studia Ecologiae et Bioethicaw* 22(3): 17–28. https://doi.org/10.21697/seb.5820.

Ekere, Romanus N., Janefrances Ihedioha Ngozi, Samson Eze Ifeanyi, and Vitus Agbazue. 2014.

"Health risk assessment in relation to heavy metals in water sources in rural regions of southeast, Nigeria." *International Journal of Physical Sciences* 9(6): 109-116. https://doi.org/10.5897/Ijps2014.4125.

Ekwok, Innocent C. 2010. *Occupational Health Hazards of Quarry Industries in Akamkpa, Cross River State.* Ph.D Thesis, Department of Geography and Environmental Science. University of Calabar, Calabar.

Eze, Bassey Eze, Josiah Nwabueze Obiefuna, and Ebin Okah Inah. 2025. "Geomorphic and Anthropogenic Influences on Street Flooding in Calabar, Cross River State, Nigeria." *Revista Riscuri Si Catastrofe / Risk and Catastrophes Journal* https://doi.org/10.24193/RCJ2025_2.

Fattah, Ghizlane, Fouzia Ghrissi, Jamal Mabrouki, and Mohamed Kabriti. 2021. "Control of physicochemical parameters of spring waters near quarries exploiting limestone rock." *EDP Sciences. E3S Web of Conferences* 234: 00018. https://doi.org/10.1051/e3sconf/202123400018#.

Ganiya, Hanzart, Ganiyah O., Bridget Onoshagbe Odiyi, and Joseph Afolabi Olajide. 2023. "Assessment of Heavy Metal Pollution from Granite Quarrying in Akure, Nigeria." *Journal of Global Ecology and Environment* 19(4): 31-39. Https://Doi.Org/10.56557/Jogee/2023/V19i3-48529.

Google. Google Earth. Version, Google LLC, 2023. Accessed 16.4.2024.

Ibanga, Emmanuel S., and V.M. Eyo. 2001. "Pulmonary Paragonimiasis in Oban Community in Akamkpa Local Government Area, Cross River State, Nigeria: Prevalence and Intensity of Infection." *Transactions of the Royal Society of Tropical Medicine and Hygiene* 95(2): 159-160. https://doi.org/10.1016/S0035-9203(01)90144-0.

Imoke, Eni Devaisam, Michael Osy Onithebor, Uqutan Ibor Uquetan, Josiah Nwabueze Obiefuna, Asor Love Joseph, Egbonyi Darlington Egbe. 2023. "Pre and Post Cement Production Era of Climatic Variables at Mfamosing Community, Akamkpa Local Government Area, Cross River State, Nigeria." *Environment and Ecology Research* 11(4): 564-578. https://doi.org/10.13189/eer.2023.110405.

Johns, Colleen Elsa, Mrudula Gattu, Samuel Camilli, Apoorva Desaraju, Narasaiah Kolliputi, and Lakshmi Galam. 2023. "The Cd/Zn Axis: Emerging Concepts in Cellular Fate and Cytotoxicity." *Biomolecules* 13(2): 316. https://doi.org/10.3390/biom13020316.

Lalik, Martina, and Dominika Dabrowska. 2024. "Groundwater Chemical Status Assessment in The Area of The Waste Landfill in Chorzow-Southern Polland." *Sustainability* 16(2): 763. https://doi.org/10.3390/Su16020763.

Liu, Xu. J. 2020. "Application of Nemerow Index Method to Evaluation of Oilfield Produced Water." *Chemical Engineering & Equipment* 2: 119–121. https://doi.org/10.19566/j.cnki.cn35-1285/tq.2020.02.051.

Liu, Meng, and Chen Shijian. 2016. "Groundwater Assessment of Honghu Area Based on The Nemerow Index and Principal Component Analysis Method." *Journal of Central China Normal University (Natural Science Edition)* 50(4): 633-640. https://doi.org/10.19603/Jcrnki.1000-1190.2016.04.025.

Maigari, A.U., Eno Ekanem, Ibrahim Garba, A. Harami, and J.C. Akan. 2016. "Health Risk Assessment for Exposure to Some Selected Heavy Metals Via Drinking Water from Dadinkowa Dam River, Gombe Abba in Gombe State, North East Nigeria." *World Journal of Analytical Chemistry* 4(1): 1-5. https://doi.org/10.12691/Wjac-4-1-1.

Majumdar, Aditi, and Kirti Avishek. 2024. "Assessing heavy metal and physicochemical pollution load of Danro River and its management using floating bed remediation." *Scientific Reports* 14(1): 9885. https://doi.org/10.1038/s41598-024-60511-x.

NIMET (Nigerian Meteorological Station). 2008. *Annual Meteorological Readings in Akamkpa Local Government Area of Cross River State – Nigeria*. Calabar: Nigerian Meteorological Station.

NPC (National Population Commission). 2006. *Final Census Report, 2006*. Abuja, Nigeria: National Population Commission.

Okafor, Odere C., and Njoku Chima. 2024. "Environmental Impact of Quarrying on Physiochemical Properties of Surface Water in Ebonyi State, Nigeria: Management of Environmental Quality." *Emerald Publishing Limited* 35(8): 1894-1911. https://doi.org/10.1108/MEQ-11-2023-0396.

Olutona, Godwin Oladele. 2023. "Health Risk Assessment of Heavy Metals in Sediment of Tropical Freshwater Stream." *Journal of The Nigerian Society of Physical Sciences* 5(1): 983. https://doi.org/10.46481/Jnsps.2023.983.

Onyele, Onyinyecgi G., and Emeka D. Anyanwu. 2018. "Human Health Risk Assessment of Some Heavy Metals in a Rural Spring, Southeastern Nigeria." *African Journal of Environment and Natural Science Research* 1(1): 15-23. https://abjournals.org/ajensr/wp-content/uploads/sites/15/journal/published_paper/volume-1/issue-1/AJENSR_xUItsoHS.pdf.

Scimeca, Manuel, Valeria Palumbo, Erica Giacobbi, Francesca Servadei, Stefana Casciardi, Elena Cornella, Federica Cerbara, Gabriele Rotondaro, et al. 2024. "Impact of the environmental pollution on cardiovascular diseases: From epidemiological to molecular evidence." *Heliyon* 10(18): e38047. https://doi.org/10.1016/j.heliyon.2024.e38047.

SDWF (Safe Drinking Water Foundation). 2017. *Mining and Water Pollution*. Mining and Water Pollution Fact Sheet. www.safewater.org.

United States Environment Protection Agency. 2017. *National Primary Drinking Water Regulations. Ground Water and Drinking Water.* Washington, DC, USA. Accessed 1 February 2025. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

Ustaoğlu, Fikret, Beyhan Taş, Yalçın Tepe, Halim Topaldemir. 2021. "Comprehensive assessment of water quality and associated health risk by using physicochemical quality indices and multivariate analysis in Terme River, Turkey." *Environmental Science and Pollution Research* 28: 62736–62754. https://doi.org/10.1007/s11356-021-15135-3.

Zhang, Qian, Minquan Feng, and Xiaoyan Hao. 2018. "Application of Nemerow Index Method and Integrated Water Quality Index Method In Water Quality Assessment of Zhangze Reservoir." *IOP Conference Series: Earth Environmental Sciences* 128: 2160. https://iopscience.iop.org/article/10.1088/1755-1315/128/1/012160/pdf.

Appendix 1

Supporting Data for Potential Health Implications of Heavy Metal Contamination of Streams Near Quarry Sites in Akamkpa, Cross River State, Nigeria

Table A1. Coordinates of the streams

The table identifies the three sampled streams, giving a short code, their names, geographic coordinates and the names of the neighbouring communities.

Stream code	Stream name	Latitude	Longitude	Community
ST 1	Plywood stream	05°13′51.6″	008°20′54.3″	Awi
ST 2	Erokud stream	05°18′40.4″	008°24′45.8″	Nsan
ST 3	Ayiponyore	05°21′53.5″	008°20′42.1″	Old Netim

Source: Fieldwork 2023.

Table A2. Population of the study communities

The table shows the population of the three communities around the streams, broken down into male, female and total population for each community.

Community	Male	Female	Total
Awi	6038	6104	12142
Nsan	15692	16080	3177
Old Netim	4171	3630	7801
Total	25901	25814	23120

Source: NPC (2006).

Table A3. Nemerow grading standard for water quality evaluation

The table presents Nemerow Pollution Index (PN) values for the streams and shows how these values translate into qualitative pollution assessment categories for each stream.

PN	Pollution Assessment
<0.59	No Pollution
0.59-0.74	Slightly Polluted
0.74-1.00	Lightly Polluted
1.00-3.50	Moderately Polluted
≥3.50	Seriously Polluted

Source: Fieldwork 2023.

Table A4. First Wet Season

The table reports further PN values and assessment classes for the individual stream codes, giving an additional view of overall pollution status per sampling point.

ST 1	PN	Pollution Assessment
N Upst	0.07	No Pollution
Dst	0.4	No Pollution
ST 2		
Upst	0.29	No Pollution
Dst	0.19	No Pollution
ST 3		
Upst	0.44	No Pollution
Dst	6.91	Seriously Polluted

Source: Fieldwork 2023.

Table A5. Second Wet Season

The table provides another set of PN values and pollution assessments, focusing on specific subsets of measurements or conditions for the same streams.

ST 1	PN	Pollution Assessment
Upst	0.02	No pollution
Dst	0.06	No pollution
ST 2		
Upst	0.01	No pollution
Dst	0.05	No pollution
ST 3		
Upst	0.02	No pollution
Dst	0.01	No pollution

Source: Fieldwork 2023.

Table A6. First Dry Season

The table summarises PN indices and pollution classes for the sampling sites under another grouping of the data, helping to compare pollution levels across streams.

ST 1	PN	Pollution Assessment
Upst	0.61	Slightly polluted
Dst	1.67	Moderately polluted
ST 2		
Upst	0.31	No pollution
Dst	0.01	No pollution
ST 3		
Upst	0.01	No pollution
Dst	0.004	No pollution

Source: Fieldwork 2023.

Table A7. Second Dry Season

The table completes the PN-based comparison of the streams, again giving the index values and their associated pollution assessment categories.

ST 1	PN	Pollution Assessment
Upst	0.64	Slightly polluted
Dst	2.39	Moderately polluted
ST 2		
Upst	0.43	No pollution
Dst	0.42	No pollution
ST 3		
Upst	0.40	No pollution
Dst	0.48	No pollution

Source: Fieldwork 2023.

Table A8. Health Risk Assessment of heavy metals for the three streams

The table summarises, for each heavy metal and stream sample, the mean concentration in water and the main risk indicators (chronic daily intake, hazard quotient and lifetime cancer risk) for adults and children.

Heavy Metals	Samples	Mean Concentration (mg/L)	CD1 Adult	HQ Adult	LCR Adult	CDI Children	HQ Children	LCR Children
Pb	ST 1 ST 2 ST 3	$2.7x10^{-4}$ 0.0 $3x10^{-5}$ *0.071	$7.4x10^{-6}$ 0.0 $8.22x10^{-7}$	$2.11x10^{-3}$ 0.0 $2.35x10^{-4}$	$6.29x10^{-8}$ 0.0 $6.98x10^{-9}$	$1.73x10^{-5}$ 0.0 $1.92x10^{-6}$	$4.94x10^{-3}$ 0.0 $5.49x10^{-4}$	$1.47x10^{-7}$ 0.0 $1.63x10^{-8}$
Cu	ST 1 ST 2 ST 3	$1.73x10^{-2}$ $9.31x10^{-3}$ $4.66x10^{-3}$ *0.239	$4.7x10^{-4}$ $2.6x10^{-4}$ $1.28x10^{-4}$	$1.18x10^{-2}$ $6.5x10^{-3}$ $3.2x10^{-3}$	- - -	$1.11x10^{-3}$ $5.95x10^{-4}$ $2.98x10^{-4}$	$2.78x10^{-1}$ $1.49x10^{-2}$ $7.45x10^{-3}$	- - -
Cr	ST 1 ST 2 ST 3	$1.1x12^{-4}$ 0.0 $2.63x10^{-5}$ *0.239	$3.01x10^{-6}$ 0.0 $7.2x10^{-7}$	$1.003x10^{-2}$ 0.0 $2.4x10^{-3}$	$1.234x10^{-7}$ 0.0 $2.88x10^{-8}$	$7.03x10^{-6}$ 0.0 $1.68x10^{-6}$	$2.34x10^{-2}$ 0.0 $5.6x10^{-3}$	$2.88x10^{-7}$ 0.0 $6.89x10^{-8}$
Zn	ST 1 ST 2 ST 3	$9.61x10^{-2}$ $2.515x10^{-2}$ $2.46x10^{-2}$ *0.001	$2.6x10^{-3}$ $6.89x10^{-4}$ $6.74x10^{-4}$	$8.67x10^{-3}$ $2.3x10^{-3}$ $2.25x10^{-3}$	- - -	$6.1x10^{-3}$ $1.61x10^{-3}$ $1.573x10^{-3}$	$2.03x10^{-2}$ $5.4x10^{-3}$ $5.24x10^{-3}$	- - -
Cd	ST 1 ST 2 ST 3	$4.3x10^{-4}$ $2x10^{-4}$ $3.75x10^{-3}$ *0.420	$1.2x10^{-5}$ $5.48x10^{-6}$ $1.03x10^{-4}$	$2.4x10^{-2}$ $1.096x10^{-2}$ $2.06x10^{-1}$	$7.32x10^{-8}$ $3.34x10^{-8}$ $6.3x10^{-7}$	$2.8x10^{-5}$ $1.29x10^{-5}$ $2.39x10^{-4}$	$9.3x10^{-2}$ $2.58x10^{-2}$ $4.78x10^{-1}$	$1.71x10^{-7}$ $7.87x10^{-8}$ $1.46x10^{-6}$
Ni	ST 1 ST 2 ST 3	$1.2x10^{-2}$ $4.1x10^{-3}$ $4.6x10^{-3}$ *0.445	$3.3x10^{-4}$ $1.12x10^{-4}$ $1.26x10^{-4}$	$1.65x10^{-2}$ $5.6x10^{-3}$ $6.3x10^{-3}$	$2.77x10^{-7}$ $9.41x10^{-8}$ $1.06x10^{-7}$	$7.7x10^{-4}$ $2.6x10^{-4}$ $2.95x10^{-4}$	$3.85x10^{-2}$ $1.3x10^{-2}$ $1.48x10^{-2}$	$6.47x10^{-7}$ $2.18x10^{-6}$ $2.48x10^{-7}$
Ba	ST 1 ST 2 ST 3	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0S

* Significance. Means with the same superscript are not significantly different.

Source: Fieldwork 2023.

Table A9. Hazard Index (HI) for Children and Adults across the three Streams

The table presents non-carcinogenic hazard indices for the streams, showing calculated HI values separately for children and for adults at each stream.

Streams	Hazard Index (HI)Children	(HI) Adults
ST 1	2.0795×10^{-1}	2.8911×10^{-1}
ST 2	5.91×10^{-1}	2.536×10^{-2}
ST 3	5.11639×10^{-1}	2.20385×10^{-1}

HI values greater than 1.0 is significant.
Source: Fieldwork 2023

Table A10. Risk Index (RI) for Children and Adults Across the three Streams

The table reports carcinogenic risk indices for the streams, indicating the estimated risk levels for children and adults exposed to heavy metals in the water.

Streams	(RI) Children	(RI) Adult
ST 1	1.253×10^{-6}	5.365×10^{-7}
ST 2	2.967×10^{-7}	1.275×10^{-7}
ST 3	1.7932×10^{-6}	7.7178×10^{-7}

RI values greater than 10^{-6} is significant.
Source: Fieldwork 2023