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# ENVIRONMENTAL POLLUTION ASSESSMENT OF SURFACE WATER IN OMEGE COMMUNITY USING CHEMICAL DATA AND RISK-BASED EVALUATION

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Abstract

Mining of mineral resources creates economic backbone for many countries but its attendant consequences on the environment and human health is far-reaching, especially when the process is done without appropriate sustainability measures. In this study, physico-chemical parameters and heavy metal load of the upstream, midstream and downstream zones of Omege River, Ebonyi State Nigeria was determined according to standard procedures. USEPA risk model was applied to estimate health risks that could be associated with five heavy metals (Zn, Fe, Cu, Pb and Cr) in the three zones of the surface water in both children and adults. EC, TDS, TSS, TS, TH, Pb and Cr were found to be above the USEPA permissible limit in the three zones of the river. CI index based on zones of the surface water was in the order of upstream < midstream < downstream while it was Zn < Cu < Fe < Cr < Pb based on the heavy metals. There was extreme high contamination by Pb in the water samples from the study area particularly in the downstream with CI reaching up 600. HQ of Pb and Cr in the three zones of the surface water was > 1 for both children and adults with that of Pb (6.64–23.57) in threatening level. HI range from 14.06 in the upstream to 3.180 in the downstream for children and from 8.71 in the upstream to 19.72 in the downstream for adults. CRI estimated for Pb and Cr were not within the acceptable limit. These results suggest potential non-carcinogenic and carcinogenic health risk in both children and adults via oral consumption of water from Omege River. Finally, this study revealed that children were at higher health risk if exposed to the heavy metals via the consumption of water from Omege River than adults.

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## Introduction

No doubt, for countries with natural mineral resources, mining is prevalent to exploit the resources to drive their economy. However, mining activities have created environmental stress particularly in developing countries like Nigeria where mining process is poorly carried out in an unsustainable manner (ADEWOYE et al. 2020). Toxic chemicals such as heavy metals are released to the environment at different stages of mining activities such as during extraction, beneficiation, and refinement. Impacts of mining during active mining period and after which the mining sites are abandoned can be felt significantly. For instance, ODUKOYA et al. (2017) reported contamination of surface water by toxic elements in adjoining active mining site; Antunes et al. (2017) documented toxic metals in an abandoned radium mine, and ADEWOYE et al. (2020) provided data of contamination of soil sample in an abandoned goldmine site.

Waste generated during mining including the mining water discharged into the environment are laden with toxic heavy metals in threatening concentrations which can leach and contaminate water resources such as surface and groundwater. Majority of heavy metals are non-essential and those that are essential can become toxic at elevated concentrations (USEPA 2014). Human exposure to these metals can elicit disease conditions and even death. In rural communities, there is poor access to portable drinking water and as such, people depend on natural water sources such as rain, groundwater and surface waters. However, surface water is the most sort-after among these water sources as they are almost without financial demand like digging a well or borehole to access groundwater and may not be seasonal like the rainwater. It was reported that 58% of households in rural communities in Nigeria lack access to safe water (WHO 2014).

Omege is a rural community situated in Ebonyi State in the southeast region of Nigeria. It is one among the several rural communities in the state that accommodates mining industries with evidence of environmental impacts from the mining activities. Recently, the use of health risk models in addition to physico-chemical indices of contaminated water has become an acceptable tool in ecotoxicology (SUNDARAY et al. 2011, OLANGUNJU et al. 2020). Unfortunately, data on the physico-chemical parameters and health risk associated with heavy metals in the major surface water of high socio-economic importance in the Omege community is lacking, hence the justification for this study.

## Materials and Methods

### Study area

Dwellers of Omege community in Ebonyi State, southeast Nigeria are mainly farmers, artisanal fishermen and workers in the mining industries. Omege River is a surface water of high socio-economic importance to the people of Omege community. The river serves various domestic and agricultural purposes including drinking, washing, recreation, irrigation, fishing and animal feeding. The community also accommodates First Patriot Limited, a mining industry that deals with extraction of lead and other useful metals.

### Sampling and analysis

Sampling was carried out in August – October, 2019; transition months from rainy season to dry season. Three sampling zones; upstream, midstream and downstream designated as UPS, MDS and DST were established during the first sampling with three (that is 1, 2 and 3) sampling points each. The coordinates of the sampling points are presented in Table 1. Water samples were collected at depth 20–25 cm directly into prewashed 1 L polyethylene bottles covered with 0.45 μm mesh. Ultrapurified 6 M $HNO_3$ was added to the filtered water samples in-situ to keep the pH below 2 and transported to the laboratory at low temperature ($\leq 4^oC$) using ice packs for ex-situ analysis. pH, electrical conductivity, total dissolved solids (TDS) and total suspended solids (TSS) were measured in-situ using a digital multi-meter (TOPAC Instruments Inc.) while total solids (TS) was calculated as the sum of TDS and TSS. Total hardness (TH), total acidity and total alkalinity were determined according to APHA (2012) and titration method was used to analyse nitrate, sulphate, chloride, fluoride. Na, Ca, Zn, K, Fe, Cu, Pb and Cr were analysed using atomic absorption spectrophotometer (AAS) after digestion using aqua regia according to USEPA (1996) and APHA (2012) guidelines. Elemental quantification analysis was done at PRODA Laboratory, Enugu, Enugu State, Nigeria. The quality assurance of elemental analysis was based on reference material CASS-5 and all elements had good recovery rates with range of 90–100%.

Table 1

Coordinates of sampling points for surface water in the study area

| Zones | Sample points | Coordinates |
|---|---|---|
| Upstream | UPS1 | N 6º 10’ 26.226”; E 8º 08’ 42.936” |
| | UPS2 | N 6º 10’ 26.142”; E 8º 08’ 42.996” |
| | UPS3 | N 6º 10’ 26.496”; E 8º 08’ 43.332” |
| Midstream | MDS1 | N 6º 10’ 17.52”; E 8º 08’ 54.108” |
| | MDS2 | N 6º 10’ 17.442”; E 8º 08’ 54.216” |
| | MDS3 | N 6º 10’ 16.728”; E 8º 08’ 56.886” |
| Downstream | DST1 | N 6º 10’ 21.204”; E 8º 09’ 15.654” |
| | DST2 | N 6º 10’ 21.126”; E 8º 09’ 15.378” |
| | DST3 | N 6º 10’ 21.624”; E 8º 09’ 15.306” |

*UPS – upstream; MDS – midstream; DST – downstream

## Statistical analysis

Statistical analysis was done using SPSS (v. 20). Range (minimum and maximum) and means are reported.

## Analysis of contamination index (CI)

Contamination index (CI) was used to evaluate elemental enrichment for the following heavy metals Zn, Fe, Cu, Pb and Cr in the surface water (upstream, midstream and downstream) using their mean values with respect to maximum permissible limit (MPL) set by USEPA (2006). CI was calculated as:

$$\mathrm{CI} = \Sigma \frac{\mathrm{Cm}}{\mathrm{MPL}} \tag{1}$$

where:
CI – contamination index
Cm – concentration of metals in the sample
MPL – maximum permissible limit.

Contamination index is classified as: CI > 5 (contaminated) 1 ≤ CI ≤ 5 (slightly contaminated) and CI < 1 (not contaminated).

## Non-carcinogenic and carcinogenic health risk evaluation

Non-carcinogenic health risk assessment predicts the likelihood of an exogenous substance to elicit various health hazards that are non-cancerous in nature while carcinogenic health risk evaluation predicts the possibility of a substance to cause cancer upon exposure (OLANGUNJU et al. 2020). Exposure to toxic heavy metals can be through ingestion, dermal or inhalation pathway. However, it has been shown that ingestion play the most important role in water contamination (GUO-LI et al. 2016, ODUKOYA et al. 2017, OLANGUNJU et al. 2020). USEPA health risk models (eqs. 2–5) were adopted and used to evaluate the risk of health hazard for water contamination via oral in children and adults. In this study, health risk estimation was done for five heavy metals which include Zn, Fe, Cu, Pb and Cr based on upstream, midstream and downstream zones of the surface water. Hazard quotient (HQ) and health index measures non-carcinogenic health risk while cancer risk index (CRI) assesses carcinogenic health risk.

$$\text{Hazard quotient (HQ)} = \frac{\text{CDI}}{\text{RFD}} \tag{2}$$

HQ > 1 means that non-carcinogenic health risk would be elicited upon exposure to a single metal:

$$\text{CDI}_{\text{Ingestion}} \frac{\text{Cm} \cdot \text{IngR} \cdot \text{EF} \cdot \text{ED}}{\text{BW} \cdot \text{AT}} \tag{3}$$

$$\text{Hazard Index (HI)} = \Sigma\text{HQ} \tag{4}$$

HI > 1 means that non-carcinogenic health risk would be elicited upon exposure to a myriad of stated metals

$$\text{CRI}_{\text{Ingestion}} = \text{CDI}_{\text{Ingestion}} \cdot \text{SF} \tag{5}$$

where:
CDI – daily chronic intake
RFD – oral reference dose based on USEPA (2009) as shown in Table 2.
Cm – concentration of heavy metals
IngR (ingestion rate of water) = 1 L for children and 2 L for adults
EF (exposure frequency) = 365 days/year
ED (exposure duration) = 6 years for children and 65 years for adults
BW (body weight) = 20 kg for children and 65 kg for adult
AT (average time) = 2190 for children and 23,725 days for adult.

SF (slope factor) via ingestion route = $8.5 \cdot 10^{-3}$ for Pb and $5.0 \cdot 10^{-1}$ for Cr. Slope factor which is the probability of developing cancer per unit exposure level of mg/kg/day has only been derived for Pb and Cr amongst the analysed heavy metals as presented in ADEWOYE et al. (2020) and as shown in Table 2. An acceptable value for cancer risk according to USEPA = $1 \cdot 10^{-6}$ to $1 \cdot 10^{-4}$.

Table 2

Physico-chemical and elemental analysis of water samples from the study area

| Parameters | Unit | Upstream | | Midstream | | Downstream | | USEPA Limit |
|---|---|---|---|---|---|---|---|---|
| | | range (min–max) | mean | range (min–max) | mean | range (min–max) | mean | |
| pH | | 6.93–7.10 | 7.01 | 6.76–7.37 | 7.14 | 6.90–7.14 | 7.03 | 6.50–8.50 |
| Conductivity | μs/cm | 14610–14740 | 14666.67 | 14950–15650 | 15240 | 14850–15960 | 15453.33 | 500 |
| TDS | mg/L | 8740–21860 | 14393.33 | 16700–20260 | 18273.33 | 18200–22460 | 20220 | 250 |
| TSS | mg/L | 1080–1740 | 1406.67 | 1120–1280 | 1186.67 | 1220–1840 | 1466.67 | 30 |
| TS | mg/L | 10140–23600 | 15800 | 17860–21380 | 19460 | 19540–24300 | 21686.67 | 500 |
| TH | mg/L | 1000–3200 | 2066.67 | 1200–2350 | 1783.33 | 2500–3500 | 2766.67 | 250 |
| Acidity | mg/L | 30–57.5 | 42.5 | 15–20 | 17.5 | 12.5–30 | 22.5 | – |
| Alkalinity | mg/L | 150–250 | 216.67 | 300–400 | 350 | 250–600 | 450 | 20 |
| Nitrate | mg/L | 0.36–0.72 | 0.48 | 0.33–0.42 | 0.36 | 0.33–0.38 | 0.36 | 10 |
| Sulphate | mg/L | 67.01–101.44 | 85.15 | 122.73–208.49 | 162.98 | 35.02–69.85 | 48.74 | 250 |
| Chloride | mg/L | 6.62–10.02 | 7.96 | 7.94–12.08 | 9.61 | 8.38–16.04 | 11.23 | 250 |
| Fluoride | mg/L | 0.15–0.32 | 0.22 | 0.11–0.2 | 0.16 | 0.22–0.26 | 0.24 | 1.50 |
| Na | mg/L | 1.60–2.74 | 2.05 | 0.60–2.17 | 1.53 | 1–2.11 | 1.5 | 60 |
| Ca | mg/L | 0.85–1.21 | 0.97 | 0.60–0.94 | 0.8 | 0.61–0.94 | 0.75 | 60 |
| Zn | mg/L | 2.25–2.41 | 2.35 | 1.88–2.6 | 2.27 | 2.14–2.45 | 2.27 | 3 |
| K | mg/L | 1.38–1.52 | 1.43 | 0.58–2.23 | 1.51 | 0.35–1.32 | 0.93 | > 200 |
| Fe | mg/L | 1.82–2.29 | 2 | 0.45–2.11 | 1.44 | 0.28–2.05 | 1.36 | 0.3 |
| Cu | mg/L | 0.68–0.82 | 0.76 | 0.55–0.8 | 0.67 | 0.09–0.96 | 0.66 | 1 |
| Pb | mg/L | 0.23–0.39 | 0.30 | 0.15–0.4 | 0.31 | 0.37–0.43 | 0.4 | 0.001 |
| Cr | mg/L | 0.01–0.19 | 0.1 | 0.14–0.52 | 0.33 | 0.19–0.38 | 0.36 | 0.005 |

# Results and discussion

## Physico-chemical parameters

The results of physic-chemical parameters and heavy metals in the water sample from the study are presented in Table 2. Generally, the magnitude of physico-chemical and elemental parameters in the water samples from the study area was in the order of upstream < midstream < downstream. The mean pH values of water samples in the upstream, midstream and downstream zones of the surface water are in the range of 7.01–7.14 which is within the USEPA limit, and which can be categorized as neutral. There was elevated level of conductivity regardless of the sampling zone which is an indication of the presence of charged ions in the water. Furthermore, TDS, TSS, TS and TH were above the USEPA limit in the three sampling zones.

Mean concentrations of nitrate and sulphates were within the permissible limit which may be an indication that pollution of the surface water was not as a result of introduction of nutrients in form of fertilizer application or faecal particles in the adjoining areas. For nitrates, the range were 0.36–0.72 mg/L, 0.33 – 0.42 mg/L and 0.33–0.38 mg/L in the upstream, midstream and downstream respectively while for sulphate it was 67.01–101.44 mg/L, 122.73–208.49 mg/L and 35.02–69.85 mg/L respectively. The irregularities of values of nitrates and sulphates could be attributed to synthetic fertilizers used in the farms adjoining the river course. All the elements analyzed were within the limit except for Pb and Cr which could be associated with the intrusions from the mining process in the study area. Other researchers have also reported high level of Pb and other toxic metals in environmental matrices sampled from adjoining areas of mining site (LIM et al. 2008, SAHA et al. 2017, ODUKOYA et al. 2017). The mean value of lead in the water sample from the study area was 0.30–0.4 mg/L while that of Cr was 0.1– 0.36 mg/L.

## Contamination index

Comparison of five heavy metals (Zn, Fe, Cu, Pb and Cr) with maximum permissible level (MPL) for drinking water according to USEPA (2006) is presented in Figures 1 to 5. Except for Zn and Fe whose values of CI were higher in the upstream than those of midstream and downstream, and for Cu with CI higher in the upstream than the midstream only; CI index for the heavy metals were generally in the order of upstream < midstream < downstream. Zn and Fe are naturally occurring metals whose presence in the environment may be due to geogenic release from the bedrock (KHAN et al. 2013). However, despite the fact that Zn and Fe are essential metals, at elevated concentrations, Fe can damage various organs (BABY et al. 2010) while Zn cause inhibition of normal respiratory function (COOPER 2008). Pb whose ore is primarily mined in the study area had the highest CI (300–660) among the other heavy metals analyzed.

The order of heavy metals based on CI was Zn < Cu < Fe < Cr < Pb. Pb is known to cause cognitive retardation children. Based on CI rating, it can be said that the surface water was not contaminated by Zn whether at upstream, midstream or downstream. There was slight contamination by Fe in midstream and downstream but significant in the upstream. CI due to Cu was 0.76, 0.67 and 1.36 in the upstream, midstream and downstream respectively, suggesting that there was no contamination due to Cu in the upstream and midstream but slightly in the downstream. There was extreme contamination by Pb in the water samples from the study area particularly in the downstream with CI reaching up 600. In addition, significant contamination by Cr occurred in the surface water as CI value for upstream, midstream and downstream was 20, 66 and 72 respectively.

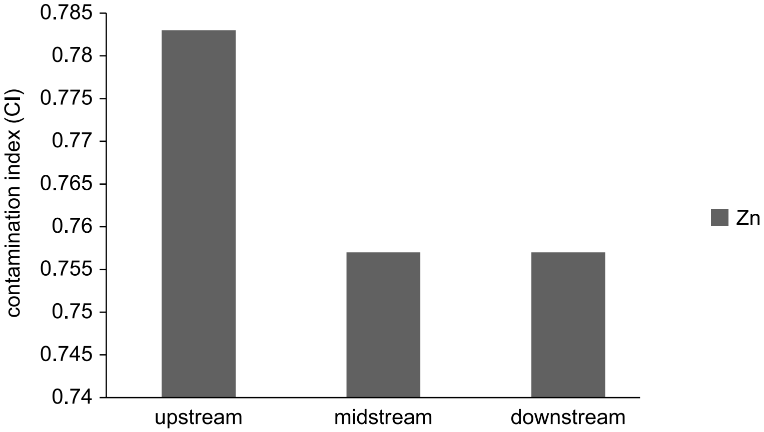


Fig. 1. Contamination index due to Zn in water sample of the study area

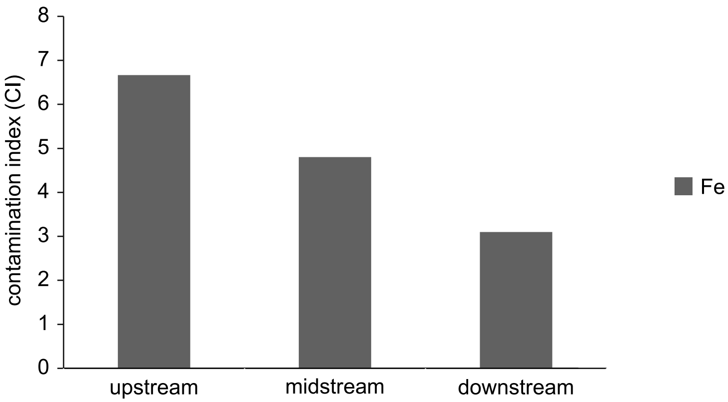


Fig. 2. Contamination index due to Fe in water sample of the study area

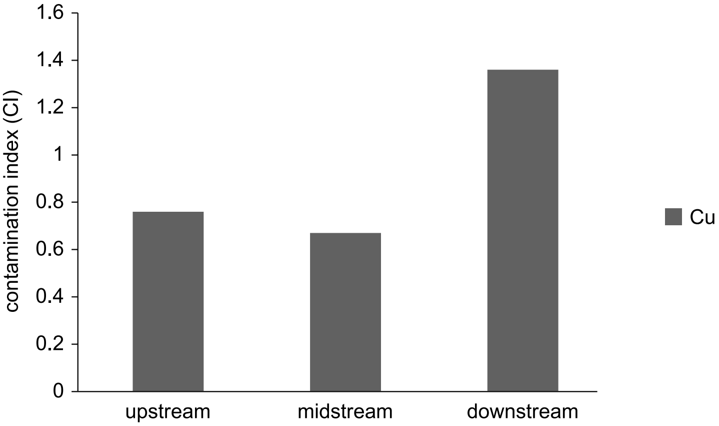


Fig. 3. Contamination index due to Cu in water sample of the study area

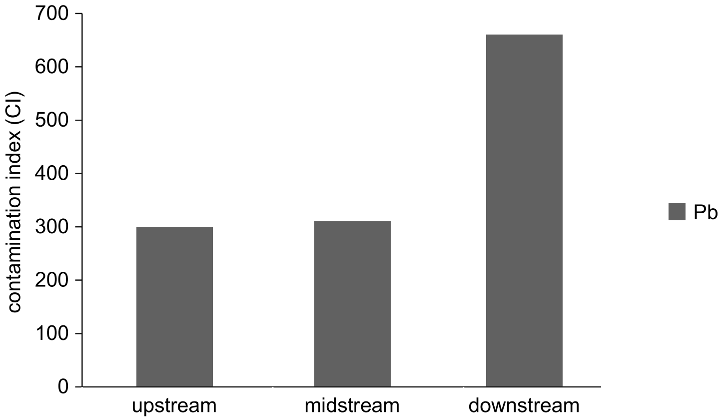


Fig. 4. Contamination index due to Pb in water sample of the study area

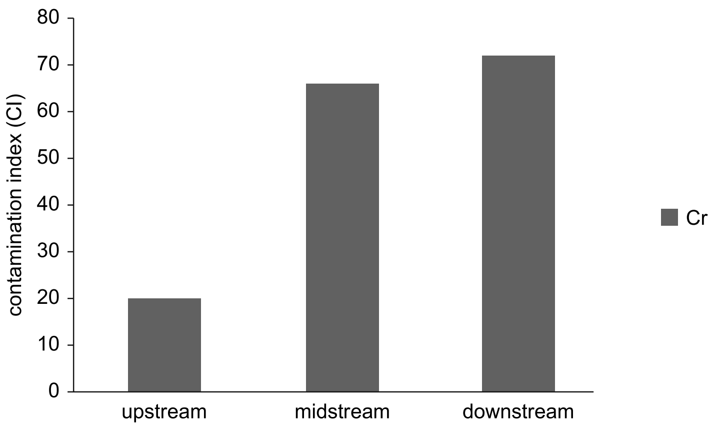


Fig. 5. Contamination index due to Cr in water sample of the study area

## Chronic daily intake (CDI), hazard quotient (HQ) and health index (HI)

Non-carcinogenic risk which is the evaluation of propensity for an individual to experience health effects that are not carcinogenic was extrapolated from CDI estimation. Estimations for CDI is presented in Table 3 while HQ and HI are presented in Table 4. Despite the larger quantity of water taken by adults daily, CDI estimated for children was greater. This may be suggestive of children's vulnerability to toxic metals in their water as compared to adults. For Pb whose CI was greatest, the CDI for children was in the range of 0.015 to 0.033 while it was 0.0093 to 0.0205 for adults.

Table 3

Chronic daily intake (CDI) of heavy metals in water samples of the study area

| Heavy metals | Chronic daily intake (CDI) | | | | | | Reference dose (RFD) | Slope factor (SF) [mg/kg/day] |
|---|---|---|---|---|---|---|---|---|
| | children | | | adults | | | | |
| | UPS | MDS | DST | UPS | MDS | DST | | |
| Zn | 0.1175 | 0.1135 | 0.1135 | 0.07285 | 0.07037 | 0.07037 | 0.3 | – |
| Fe | 0.1 | 0.072 | 0.0465 | 0.062 | 0.04464 | 0.02883 | 0.3 | – |
| Cu | 0.038 | 0.0335 | 0.068 | 0.02356 | 0.02077 | 0.04216 | 0.04 | – |
| Pb | 0.015 | 0.0155 | 0.033 | 0.0093 | 0.00961 | 0.02046 | 0.0014 | 0.0085 |
| Cr | 0.005 | 0.0165 | 0.018 | 0.0031 | 0.01023 | 0.01116 | 0.003 | 0.5 |

*UPS – upstream; MDS – midstream; DST – downstream

Table 4

Hazard quotient, health index and cancer risk index of heavy metals in water samples of the study area

| Heavy metals | Hazard quotient (HQ) | | | | | | Cancer risk index (CRI) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | children | | | adults | | | children | | | adults | | |
| | UPS | MDS | DST | UPS | MDS | DST | UPS | MDS | DST | UPS | MDS | DST |
| Zn | 0.39 | 0.38 | 0.38 | 0.24 | 0.23 | 0.23 | – | – | – | – | – | – |
| Fe | 0.33 | 0.24 | 0.16 | 0.21 | 0.15 | 0.10 | – | – | – | – | – | – |
| Cu | 0.95 | 0.84 | 1.70 | 0.59 | 0.52 | 1.05 | – | – | – | – | – | – |
| Pb | 10.71 | 11.07 | 23.57 | 6.64 | 6.86 | 14.61 | 1.00E-04 | 1.32E-04 | 2.81E-04 | 7.91E-05 | 8.17E-05 | 1.74E-04 |
| Cr | 1.67 | 5.50 | 6.00 | 1.03 | 3.41 | 3.72 | 2.50E-03 | 8.25E-03 | 9.00E-03 | 1.55E-03 | 5.12E-03 | 5.58E-03 |
| Health index (HI) | 14.06 | 18.03 | 31.80 | 8.71 | 11.18 | 19.72 | – | – | – | – | – | – |

*UPS – upstream; MDS – midstream; DST – downstream

HQ for the five heavy metals (Zn, Fe, Cu, Pb and Cr) in the upstream, midstream and downstream revealed that Zn, Fe and Cu (except Cu at the downstream) posed no risk of health to both children and adults since their HQ was < 1. Pb and Cr had HQ in samples from the three zones of the surface water values > 1 in both children and adults. However, Pb had an extremely high HQ in the water sample from the study area. For instance, upstream, midstream and downstream sample had HQ of 10.71, 11.07 and 23.57 respectively in children while it was 6.64, 6.86 and 14.61 respectively in adults. This result further established that children are more predisposed to health risks compared to adults as submitted in the findings of OLANGUNJU et al. (2020). HI associated with water consumption regardless of the zones from which the water was collected in the study by children and adults with respect to Zn, Fe, Cu, Pb and Cr showed values outside the acceptable non-carcinogenic health risk. HI range from 14.06 in the upstream to 3.180 in the downstream for children and from 8.71 in the upstream to 19.72 in the downstream for adults. There is possibility of heavy metal release particularly Pb from the mining process in the adjoining area of the Omege River to the surface water and may be responsible for the possible non-carcinogenic health risk evaluated if water from the surface water is consumed by children and adults.

## Cancer risk index (CRI)

CRI has been applied to determine the potential of developing cancer due to exposure to certain metals. CRI as estimated for upstream, midstream and downstream in children and adults as presented in Table 4 shows that Pb and Cr would elicit carcinogenesis in the two age groups irrespective of the zones of Omege River that they fetch water from for drinking. Furthermore, the results showed that drinking from downstream predisposes one more to cancer risk and children were at higher risk than adults. This is consistent with the report of ADEWOYE et al. (2020) that exposure to Pb outside the permissible cancer risk of would predispose individuals to risk of having cancer particularly in children. CRI due to Pb was in the range of 7.91E-05 in the upstream to 2.81E-04 in the downstream in both children and adults. Meanwhile, it was in the range of 1.55E-03 to 9.00E-03 for Cr in both age groups.

## Conclusion

This research assessed the health status of Omege River in Ebonyi State, southeast Nigeria using physico-chemical parameters and health risk-based evaluation of five heavy metals. The study elucidated that even though mining may be a source of income for economic viability of a country, its impacts on the environment must be prioritised as the revenue generated from mining may not be enough to solve the consequential problems that will be posed to the environment as well as human health. Amongst Zn, Fe, Cu, Pb and Cr analyzed, Pb and Cr were above the permissible limit. HQ for the five heavy metals in the upstream, midstream and downstream zones showed that Zn, Fe and Cu (except for Cu at the downstream) posed no risk of health to both children and adults since their HQ was < 1. However, Pb and Cr had HQ in samples from the three zones of the surface water with values > 1 for both children and adults. It was noted that Pb had an extremely high HQ in the water sample from the study area. HI and CRI estimated for the selected heavy metals were not within the acceptable limit, suggesting potential non-carcinogenic and carcinogenic health risk in both children and adults via oral consumption of water from Omege River. Finally, this study revealed that children were at higher health risk if exposed to the heavy metals via the consumption of water from Omege River than adults.

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