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HEALTH RISK HAZARD OF HEAVY METAL IN DRINKING WATER SOURCE AROUND OWUKPA COAL MINE FIELD, BENUE STATE, NIGERIA

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ABSTRACT

Concentrations of six elements were examined in water. Average concentration obtained from AAS analysis of the samples showed Ni (0.60), Fe (0.80), Cd (0.14), Cr (0.38), Pb (0.84), and Mn (0.73) in (mg/L). The concentration varied in the order: Pb>Fe>Mn>Ni>Cr>Cd for water samples. It was observed that the trend of EDIs for heavy metals in the water samples analyzed increased in the order: Fe>Mn>Ni>Pb >Cr>Cd. The HRIs of Ni, Mn, Cr and Fe were lower than 1 (HRI >1) except for Cd and Pb, with Carcinogenic Risk values of Ni (0.0041), Fe (0.0063), Cd (0.0076), Cr (0.0010), Pb (0.00), and Mn (0.0057), respectively.

Keywords: Atomic absorption spectroscopy, carcinogenic risk, heavy metal.

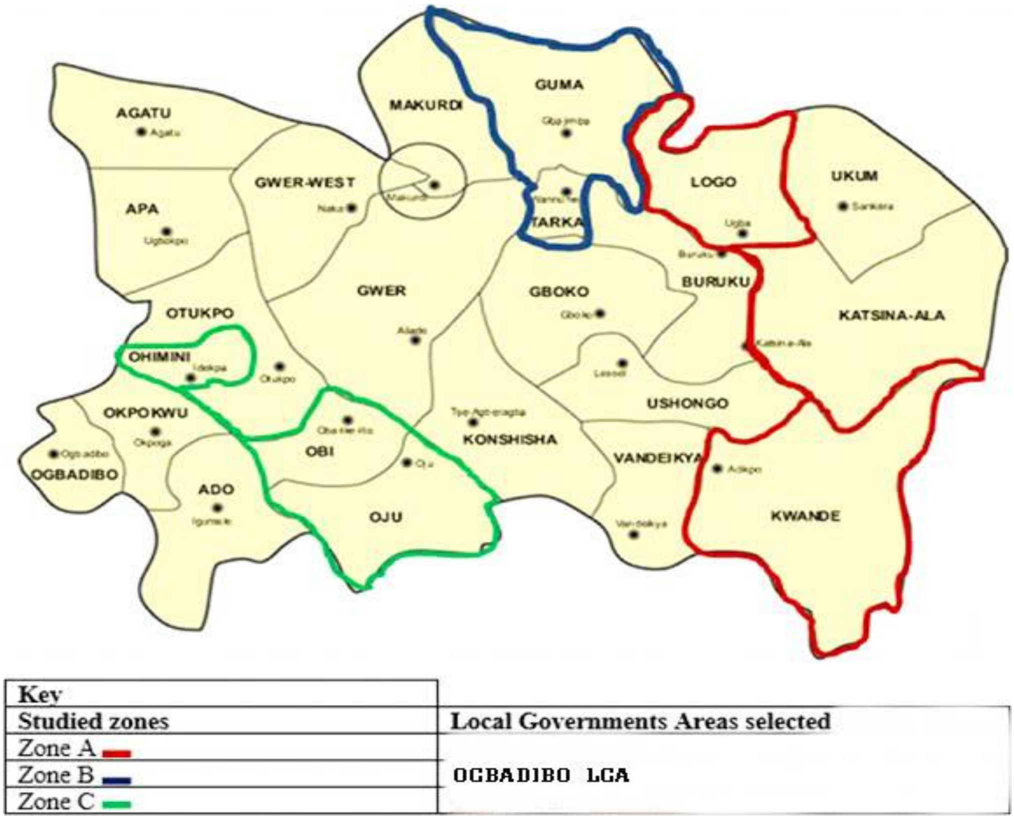
INTRODUCTION

The main element of the hydrosphere on Earth is water, which is also the fluid used by all known living things for both industrial and non-industrial activities. It is an inorganic chemical substance with a density of 99 kg/m^3, is clear, almost colorless, and has no flavor or odor. When contaminated, this material can harbor germs that cause cholera, diarrhea, dysentery, typhoid, hepatitis A, and polio, among other diseases (Dhriti and Mahendra, 2021), thereby making it unfit for domestic and industrial purposes. Nearly 297,000 children under the age of five have recorded illnesses related to inadequate hygiene, poor sanitation, or contaminated drinking water each year, according to the UN (2016). There are several causes of water pollution arising from heavy metals and other toxic pollutants. Runoff from industries such as mining, pharmaceutical, Agricultural etc. carries heavy metals. According to Musilova et al. (2016), most of these metals accumulate within the soil and sediment found in aquatic environments. Taking Owukpa's water sources as a case in point, the water in this area has been heavily contaminated with metals discharged from mining operations. Analysis of the physicochemical properties of water bodies in Owukpa has indicated a significant level of acidity (Sesugh *et al*., 2021).

Even at very low concentrations, heavy metals may be extremely poisonous and cause severe health issues for both people and other ecosystems. The toxicity of a metal is influenced by several factors, such as the specific species it affects, its biological role, its chemical properties, and the duration of exposure to the metal. Consequently, when heavy metals are introduced into water, all living organisms are eventually affected. Humans are particularly susceptible to heavy metals thus making it harmful to human health. According to Lee *et al*. (2012), this is caused due to the fact that heavy metal concentrations rise up the food chain.

Study Area

This research was conducted in Owukpa. The research region is situated between latitudes 6º30' and 7º26'N and longitudes 7º10' and 7º30'E. Owukpa is located in Ogbadibo LGA, Benue State, Nigeria. It has an abundant coal resource with 80 million tons of total reserves, which Owukpa Consolidated Mines Limited is actively mining. Orokam borders Owukpa in the west and has a border with Obollo Eke in Udenu LGA, Enugu State. Its total size is approximately 1286 km^2. The study area has two seasons (rainfall and dry conditions). From April through October, there is a seven-month rainy season. Between 1,200 and 1500 mm of rain fall are recorded annually. In March and April, daytime temperatures are often fairly high. In the summer, the region's daily maximum and lowest average temperatures are 35°C and 21°C, respectively, and in the winter, they are 37°C and 16°C. While sandstone makes up the majority of the meta-sediments, these sediment layers also comprise limestone, shale, quartzite and siltstone. The local population in Owukpa predominantly relies on water sourced from streams, rivers and wells to serve various domestic needs, such as drinking, cleaning and bathing. This water are also used during the dry season for irrigation and they turn to rainwater for these purposes during the rainy season.



MATERIAL AND METHODS

Collection and preparation of water samples

Total numbers of eleven (11) water samples were obtained from different sites in Owukpa for the analysis as follows; five (5) water samples were fetched from the Eyari stream where the resident gets their drinking water. Five (5) water samples fetched from the mining reservoir and a control sample was fetched from Okpoga River (8 km away) using a clean polyvinyl chloride (PVC) plastic bottles. These plastic bottles were first cleaned with detergent, leached with 1:1 HCl, correctly risen with distilled deionized water, and properly labeled in order to eliminate any trace metals that were sticking to the surface (Sesugh *et al*., 2021).

Digestion of water samples

This was conducted using 20 cm^3 HNO_3, 1 cm^3 of H_2SO_4, and 2 cm^3 of $HClO_4$. Each of the samples was heated at 250 ºC for 22 to 55 minutes slowly in a fume cupboard for complete escape of the brown fumes, and the appearance of white fume, then allowed to cool. After which the resultant was diluted with deionized water. The filtrate was then diluted to mark (Sesugh *et al.,* 2021).

Elemental Analysis

Each metal under investigation was dissolved in deionized water to create solutions. 1.0 g sample of each solid metal was mixed with a 1:1 nitric acid solution in a 10 mL volume and then poured into a 1000 mL volumetric flask. It was then diluted with distilled water to form the initial stock solution. Each metal's 1000 mg/L stock solution was used to create standard solutions. Through multiple dilutions of the stock solution, a calibration curve was created. The metals studied included cadmium (Cd), chromium (Cr), nickel (Ni), iron (Fe), manganese (Mn) and lead (Pb) and their reference solutions were adjusted to a 2.5 pH with the addition of 1 M nitric acid.

To analyze these solutions, each standard and sample was aspirated directly into a flame, and the absorbance was measured using Ice 3000 AA02134104 v1.30 Thermo Scientific Atomic Absorption Spectrophotometer equipped with hollow cathode lamps emitting wavelengths specific to each metal: 228.8 nm for Cd, 357.9 nm for Cr, 232.0 nm for Fe, 283.2 nm for Ni, 279.5 nm for Mn, and 248.3 nm for Pb. After each sample, the nebulizer, atomizer, and burner were cleaned thoroughly with deionized water. With the highest operating standard solution and a blank, the equipment's stability was periodically tested. In order to get the highest absorbency and linear response while aspirating established standards, the settings were tuned prior to sample analysis.

Health Risk Assessment

This was conducted by the used in the work of Sajjad *et al*. (2009).

Estimated Daily Intakes (EDI) of heavy metals

This was calculated by dividing the average weight of individuals in the given environment by the weight of the specific food item they consumed, and then multiplying this by the corresponding average concentration of the metals found in food samples (Katsikantami *et al*., 2019). Daily intakes of metals were determined for average weight of infant (5 kg, children (15 kg) and adult (60kg).

$$EDIs = \frac{C_{Metal} \times D_{Intake}}{B_{Average\ weight}} \quad \text{equation (1)}$$

Where,

C_{Metal} = Concentration of heavy metals;

D_{Intake} = Daily intake of heavy metals;

$B_{Average\ weight}$ = 65 kg (Average adult body weight)

Health Risk Index (HRI)

This was estimated by dividing the Daily Intake of Metals (DIM) by the Reference Oral Dose (RfD) using the formula given below:

$$HRI = \frac{DIM}{RfD} \qquad \text{equation (2)}$$

HRI<1 signifies that the health risk expose to humans and animals is low and considered safe (Bo *et al*., 2009).

Carcinogenic Risk (CR)

Carcinogenic risk (CR) represents an individual's lifelong likelihood of developing cancer due to potential exposure to a substance suspected of causing cancer. To determine the cancer risk, the Environmental Protection Agency (USEPA) provides a Cancer Slope Factor (CSF), which is then applied by multiplying it with the estimated daily consumption (USEPA, 2010). Acceptable risk values vary from 10^{-4} to 10^{-6} (USEPA, 2010). The formula for estimating CR is given below:

$$CR = CSF \times EDI \qquad \text{equation (3)}$$

Where, CSF is the carcinogenic slope factor of 0.91 $(mg/kg/day)^{-1}$ for Ni, Zero slope factor for Fe, 6.3 $(mg/kg/day)^{-1}$ for Cd, 0.5 $(mg/kg/day)^{-1}$ for Cr, 0.0085 $(mg/kg/day)^{-1}$ for Pb, and 0.000 $(mg/kg/day)^{-1}$ for Mn (USEPA, 2010).

Sample Description

Water samples were obtained from Eyari river where the residence gets their drinking water and the mining reservoir while the control sample from Okpoga, where was considered not to under the influence of mining process. These water samples were given labels as follows: S1 – S10 for the samples from Eyari River and the mining reservoir, and C1 for the control sample from Okpoga.

RESULT AND DISCUSSION

Average concentration (mg/L) of heavy metal in water around Owukpa mine fields are shown in Table 1 below.

Table 1: Heavy metal concentrations (mg/L) in water samples

SAMPLE	Cd	Cr	Fe	Mn	Ni	Pb
C1	0.05 ± 0.01^{b}	0.07 ± 0.01^{d}	0.21 ± 0.01^{e}	0.51 ± 0.01^{c}	0.30 ± 0.01^{f}	ND
S1	0.14 ± 0.02^{b}	ND	0.27 ± 0.01^{c}	0.39 ± 0.04^{d}	0.37 ± 0.01^{d}	0.61 ± 0.01^{e}

S2	0.11±0.01^{b}	0.12±0.01^{b}	0.29±0.03^{c}	0.43±0.04^{e}	0.38±0.01^{d}	ND
S3	0.13±0.01^{b}	0.55±0.01^{d}	0.32±0.05^{c}	0.34±0.01^{c}	0.49±0.03^{d}	ND
S4	0.15±0.03^{b}	0.15±0.03^{b}	0.46±0.01^{c}	0.50±0.06^{c}	0.51±0.03^{c}	ND
S5	0.14±0.01^{b}	0.08±0.02^{b}	0.96±0.02^{d}	ND	0.34±0.01^{c}	1.11±0.04^{e}
S6	0.13±0.01^{b}	ND	0.76±0.03^{d}	1.07±0.02^{e}	0.58±0.03^{c}	0.74±0.08^{d}
S7	0.15±0.01^{c}	0.07±0.01^{b}	1.86±0.04^{f}	1.06±0.02^{e}	0.68±0.01^{d}	ND
S8	0.12±0.01^{b}	ND	0.82±0.08^{d}	0.97±0.06^{de}	0.61±0.01^{c}	0.94±0.06^{e}
S9	0.15±0.01^{b}	1.05±0.04^{e}	1.01±0.04^{e}	0.83±0.02^{d}	0.72±0.02^{c}	ND
S10	0.16±0.02^{a}	0.39±0.01^{b}	0.87±0.01^{e}	1.17±0.01^{f}	0.67±0.04^{c}	0.79±0.02^{d}
Mean±SD	0.14±0.01	0.24±0.01	0.76±0.03	0.68±0.03	0.54±0.02	0.42±0.02
Range	0.11 - 0.16	0.07 - 1.05	0.27 - 1.86	0.34 - 1.17	0.34 - 1.30	0.61- 1.11

Results are expressed in mean ± standard deviation of triplicate determination. Results with same alphabet superscript show no significant difference while results with different alphabet superscript within the row show significant difference at $p < 0.05$. Where C1 represent control sample and S1 to S10 represent water sample 1 to sample 10.

ND = Not detected.

The result of heavy metal analysis of water samples from Owukpa mine filed revealed the following mean concentration and range values of heavy metals: Cd 0.14±0.01 mg/L (0.11 – 0.16 mg/L), Cr 0.24±0.01 mg/L (007 – 1.05 mg/L), Fe 0.76±0.03 mg/L (0.27 – 1.86 mg/L), Mn 0.68±0.03 mg/L (0.34 – 1.17 mg/L), Ni 0.54±0.02 mg/L (0.34 – 1.30 mg/L), Pb 0.42±0.02 mg/L (0.61 – 1.11 mg/L).

Table 2: Estimated Daily Intake (mg/day/kg.bw) of Heavy Metals in Water, Vegetable and Cow Milk Samples

Water						
Age	**Cd**	**Cr**	**Fe**	**Mn**	**Ni**	**Pb**
Infant	0.014	0.024	0.076	0.068	0.054	0.042
Children	0.019	0.032	0.101	0.091	0.072	0.056

Adult	0.005	0.009	0.027	0.024	0.019	0.015

Table 3: Health Risk index (HRI)/ Carcinogenic risk of Heavy Metals in Water

Samples	**Cd**	**Cr**	**Fe**	**Mn**	**Ni**	**Pb**
Health Risk index	1.2000	0.6670	0.0090	0.0410	0.2250	1.0000
Carcinogenic Risk	0.0076	0.0010	0.0063	0.0057	0.0041	0.0000

Discussion

Heavy Metal Concentrations in Water Samples

The result of heavy metals concentrations (mg/L) determined in water samples collected from different water sources around coal mine field were presented in Table 1.

The concentration of Cadmium (Cd) in the water samples were within the range of 0.11 to 0.16 mg/L, with a mean level of 0.14±0.02 mg/L. Cd showed highest concentration in sample S10 at 0.16 mg/L, while the lowest was seen in sample S2 at 0.11 mg/L. The mean Cd concentration exceeded that of the control sample, which was at 0.05 mg/L. The average concentration of Cd was higher than the WHO limit of 0.05 (WHO, 2004). This level of contamination may arise from mining activities and farming practices in the study area. On the contrary, a similar investigation recorded no or less impact of mining activities on water around mining area in Osun State, with mean concentration 0.01±0.04 mg/L of Cd which was also below the permissible limit (Taiwo, and Awomeso, 2017). Similarly, Mohan *et al*., (2015) also reported concentration of 0.08±0.02 mg/L in river water around artisanal gold mines in Kibi area, Ghana. This further implies that aside mining activities other factors such as farming, improper disposal of waste can influence the presence of Cd in water.

Cadmium level beyond the WHO limit may cause adverse health effects such as kidney damage, bronchitis, and osteomalacia (Kapoor and Singh, 2021). According to Huang et al. (2014), Cd is known to harm body cells by making them more permeable and allowing additional heavy metals to enter them.

Chromium (Cr) concentrations in the water samples varied significantly such that the highest was found in sample S9 at 1.05 mg/L, while the lowest concentration was in sample S7 at 0.07 mg/L, with mean concentration of 0.24±0.01 mg/L. The mean concentration value (0.24±0.01 mg/L) was notably higher than the control sample, which had a concentration of 0.07 mg/L. However, Cr was not present in samples (S1, S6, and S8) as presented in table 1. Cr was found to have mean value of 0.38±0.35 mg/L. The mean value (0.24±0.01 mg/L) observed is lower than that mean concentration of (0.36±0.21 mg/L) in water from streams in Arufu community due to galena mining as reported by Yebpella *et al.,* (2020), but higher compared to Cr value (0.009 mg/L) in water sampled beside quarries and barite mine sites in central Cross River (Ochelebe *et al*., 2020). The mean Cr concentration reported observed (0.24±0.01 mg/L) is above the permissible level for Cr (0.05 mg/L) set by WHO (2004), thus indicating they were polluted with chromium due to the mining activities within the vicinity. Chromium (Cr) is essential for the metabolism of glucose, fat, and cholesterol. In addition to hyperglycemia, increased body fat, and lower sperm count, chromium levels beyond the WHO acceptable limit are hazardous and carcinogenic (Wise *et al*., 2019). The symptoms of chromium deficiency, which are frequently improved by more dietary chromium, are comparable to those of diabetes and cardiovascular illnesses with maturity-onset.

As shown in Table 1, iron (Fe) was determined and found to be present in all the samples analyzed. Iron (Fe) concentration (mg/L) was highest in sample S7 (1.86 mg/L) and lowest in sample S1 (0.27 mg/L). The water samples recorded mean concentration of 0.76±0.03 mg/L which was slightly above the concentration of Fe in the control sample (0.61 mg/l). This shows that the prevalence of Fe in the control area may possibly be due to the geology of the area. Importantly, the observed average Fe concentrations were above the WHO limit of 0.03 mg/L (WHO, 2004), indicating a high presence of iron in the water bodies, making it unsuitable for consumption by the area's inhabitants.

Similar trend was observed by Kabir *et al*., (2017) in assessing Fe concentration in water sampled at abandoned lead-zinc mines in Yelu, Bauchi State. The concentrations varied from 0.58 to 0.78 mg/L and are above the limit of 0.03 mg/L. The high concentration just like the present study was attributed to industrial activities in the study areas. Excess intake of ion can trigger vomiting, stomach pain nausea and constipation (Stoffel *et al*., 2020).

Manganese (Mn) concentrations in each of the samples analyzed were all detected except in sample S5. The concentrations varied from 0.34 - 1.17 mg/L in the water samples and showed a mean concentration of 0.68±0.03 mg/L. Manganese concentration was highest in sample S10 (1.17 mg/L) and sample S3 had the lowest concentration (0.34 mg/L). These were observed to be higher than the control area (0.51 mg/L) which suggests that water sources around the study area are polluted of Mn which may be due to the mining activity in the area or through industrial discharge. The values reported in this work revealed that Mn concentration were above the WHO limit of Mn (0.050 mg/L) (WHO, 2004). However, Manganese is a mineral that is found naturally in the environment. A similar was results obtained from heavy metal analysis of water sampled beside quarries and barite mine sites in central Cross River showed a range of Mn concentration of 0.983 to 1.437 mg/L with a mean concentration of 1.23±0.33 mg/L (Ochelebe *et al*., 2020). This affirm the fact that mining influence presence of manganese. Manganese helps to enhance plants and animals growth. Mn levels above the WHO recommended limit can have dangerous effects on human lungs and brains as well as severe skeletal and reproductive problems in animals (Jarup, 2003).

Nickel (Ni) concentrations in the water samples were 0.34 to 0.72 mg/L with mean concentration of 0.54±0.02 mg/L. The average concentration was higher than the control sample concentration of 0.30 mg/L obtained. Highest Ni concentration was observed in sample coded S9 (0.72) and lowest concentration in sample S5 (0.34). The results obtained suggest water bodies contain high level of Ni than the WHO limit of 0.02 mg/L (WHO, 2004). Udiba *et al.,* (2018) reported an average concentration of Ni (0.06±0.33 mg/L) in ground water obtained around mining site in Dareta Village, Zamfara which is lower than 0.54±0.02 mg/L obtained in the present work. Overexposure to nickel can lead to various health issues, including allergies, cardiovascular and renal problems, lung fibrosis, and lung and nasal cancer. Similar to other deficiencies, nickel deficiency also causes lung fibrosis, contact dermatitis, headaches, gastrointestinal signs, and respiratory manifestations. (Genchi *et al.,* 2020). While natural activities such as eruption from volcanoes, weathering of rocks can be a source of Ni contamination in water, anthropogenic activities such as the mining of coal which releases Ni in the environment.

Lead (Pb) was not present in most of the samples (S2, S3, S4, S7 and S9), including the control sample. However, Pb concentrations ranged from 0.61 to 1.11 mg/L. The average concentration of Pb in the water sample is 0.84±0.19 mg/L. Highest lead concentration was in sample S5 (1.11 mg/L) while lowest concentration was in sample S1 (0.61 mg/L). Despite Pb not detected in most of the sample, their mean concentration revealed they were above the Pb acceptable limit of 0.01 mg/L (WHO, 2004), thus indicating that the water sources were highly polluted with lead. This can be attributed to the mining of activities. Lead is toxic and has adverse effects even at low concentration. Lead levels above the WHO acceptable limit are linked to learning disabilities in children and can penetrate the blood-brain barrier in adults. According to Ara and Usmani (2015), adults who have recently been poisoned with organic lead compounds may develop lead encephalopathy. Due to lead's high level of toxicity, monitoring the amount of lead in food is crucial (WHO, 2004).

Estimated Daily Intake

The study determined the EDI of heavy metals by calculating the mean concentrations of individual heavy metals and accounting for the average weight of infants (5 kg), children (15 kg), and adults (70 kg). The results indicated that infants had the highest EDIs for heavy metals, and the trend of EDIs (mg/day/kg) from water samples followed this order: Fe (0.076, 0.101, 0.027) > Mn(0.068, 0.091, 0.024) > Ni(0.054, 0.072, 0.019) > Pb(0.042, 0.056, 0.015) > Cr(0.024, 0.032, 0.009) > Cd (0.014, 0.019, 0.005) for infant, children and adult respectively. Tracing a contaminant's path from source to human is crucial for estimating the degree of exposure. Oral consumption is thought to be the main route for exposure via the food chain, however there are other probable routes for exposure to humans, such as cutaneous contact and inhalation (Rizwan *et al*., 2017). WHO (2002) set tolerable intakes for Cd, Cr, Fe, Mn, Ni and Pb to be 0.0600, 0.0160, 0.8, 0.66, 1.4 and 0.214 respectively (Parisa, 2018). This shows that estimated daily intake for Cr, Ni, Pb and Cr were still within the tolerable limit, however, Cr daily intake were higher in the analyzed samples for children and infant. Generally, Fe and Mn record EDI values above the tolerable limit, an indication of health risk.

The Health Risk Index (HRI)

The Health Risk Index (HRI) serves as a valuable tool for gauging the potential harm arising from the consumption food contaminated by heavy metals (Ihedioha *et al*., 2016). The results are shown in Table 3. Cr, Fe, Mn and Ni had value less than 1 while the HRIs of Cd, Pb for Water sample were greater than 1, which show that individuals residing near coal mining sites face an elevated health risk due to metal exposure. According to Okunola *et al*., (2011), the amount of metal consumption does not match the amount of pollutants absorbed since some of the heavy metals may be eliminated while the rest may accumulate in body tissues and harm human health. According to Khan et al. (2018), an HRI value below 1 (HRI < 1) is considered an acceptable level of health risk for the population, whereas an HRI equal to or exceeding 1 (HRI ≥ 1) indicates an unacceptable health risk (Okunola *et al*., 2011).

Carcinogenic Risk

The average daily consumption (mg/kg day) over a lifetime) was multiplied by a cancer slope factor (SF) shown in Table 3 to get the cancer risk (CR). Cancer Risk is the lifetime cumulative likelihood of a person having cancer (Kamiska *et al*., 2015). According to the guidelines provided by USEPA, acceptable risk limits for carcinogens range from 1 in 10,000 (10^{-4}) to 1 in 1,000,000 (10^{-6}), indicating the risk of developing cancer (USEPA, 2010). For example, a CR of 10^{-4} implies that one in 10,000 people is at risk of developing cancer.

Table 4.10 shows Carcinogenic Risk range values of Ni (0.0041), Fe (0.0063), Cd (0.0076), Cr (0.0010), Pb (0.0000), and Mn (0.0057), respectively, all greater than 10^{-4}, except for Pb with zero CR. This suggests that water in the area pose a significant risk of cancer. Cd, Cr, and Ni were of highest concern due to their carcinogenic nature (Stevens *et al*., 2011, Wang *et al*., 2015). Mn however is known to be non-carcinogenic. The USEPA (2010) deemed a risk of an extra case of human cancer occurring during a lifespan of 70 years (10^{-6} – 10^{-4}) to be tolerable or insignificant.

CONCLUSION

The issue of health risk hazards associated with the level of heavy metals in water sources surrounding the Owukpa coal mine field in Benue State, Nigeria, is a matter of utmost concern. This study has shed light on the significant implications of contamination from heavy metals in water sources, highlighting the potential threats it poses to the well-being of the local population. This study reveals that water samples concentrations of the analyzed metal Cd, Cr, Fe, Mn and Pb were above the WHO recommended guideline or permissible limit, which is in agreement with data obtained for physicochemical parameters of water bodies in Owukpa with significant level of acidity (Sesugh *et al*., 2021). The study also revealed that the health risk index, carcinogenic risk and estimated daily intake of the analyzed metals call for concern most especially for infants, as it pose serious short and long term adverse effect on individuals in Owukpa community. The presence of these heavy metals in water sources requires that urgent measures should be placed to mitigate these risks and safeguard the health of the communities relying on these water supplies.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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