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Health-Risk Assessment of Heavy Metals in Drinking Water Obtained from Public Primary Schools in Akwa Ibom State, Nigeria

Onyeukwu Nkechi Jovita[1*], Okonkwo Ogochukwu Emmanuel[1], Osom Unwana Akpan[2], Anah Victor Udoh[3], Bunu Samuel Jacob[4]

[1]Department of Pharmacology and Toxicology, Faculty of Pharmacy, University of Uyo, Akwa Ibom, Nigeria
[2]Health Centre, University of Uyo, Uyo, Akwa Ibom State, Nigeria
[3]Department of Pharmaceutical and Medicinal Chemistry, Faculty of Pharmacy, University of Uyo, Nigeria
[4]Department of Pharmaceutical and Medicinal Chemistry, Faculty of Pharmacy, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

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***Corresponding author:** Onyeukwu Nkechi Jovita
Department of Pharmacology and Toxicology, Faculty of Pharmacy, University of Uyo, Akwa Ibom, Nigeria

Abstract

Original Research Article

The presence of heavy metals in drinking water sources poses significant public health and environmental concerns, especially in children which affect their development when they exceed their permissible limits. This study assessed the levels of arsenic, cadmium, iron, lead, and vanadium in water obtained from drinking water bottles among children from three locations; St. Joseph Primary School (L1), Government School Ediene II (L2), and Government School Ibiaku Itam II (L3) of Uyo, Abak and Itu Local Government Areas respectively, in Akwa Ibom State, Nigeria. Seventy-five water samples (five water samples from each class from primary 1 – 5, which amounted to 25 water samples from each school) were collected from these schools, and levels of the specified heavy metals were quantified with an Atomic Absorption Spectrophotometer. The health risk analysis was assessed using Estimated Daily Intake, Hazard Index, and Cancer Risk. The concentration of lead, iron, and cadmium in the three schools was above the permissible standards. Lead had the highest EDI, followed by iron and cadmium; arsenic and vanadium were within the permissible limit. The Total HI of arsenic, cadmium, iron, lead, and vanadium was <1, indicating low non-carcinogenic risk. The total Cancer Risk was all within the permissible limit, indicating low cancer risk, although, the contribution of lead, iron, and cadmium was significant. The outcomes showed that the concentration of some heavy metals in the water being consumed by people in the study locations is more than the required limits. The result demonstrated both low non-carcinogenic risk and cancer risk.

Keywords: Heavy metals, water, children, risk analysis, public health, Akwa Ibom.

INTRODUCTION

Water is the most readily available and vital material for life on Earth (Tom, 2021). The World Health Organization (WHO) estimates that 844 million people worldwide do not have access to safe drinking water, and that 230 million people spend more than 30 minutes per day collecting water from piped water, protected wells and springs, rainwater, and packaged/delivered water (WHO, 2017). Groundwater is one of the planet's most vital renewable and widely distributed resources, as well as a major source of water supply worldwide (Scanlon, 2023). Surface water is also used for irrigation, wastewater treatment for livestock, industrial purposes, hydropower, and recreation. According to the Environmental Protection Agency (EPA), surface water accounts for approximately 68% of water given to communities (USEPA, 2017). Surface water is classified into three types: permanent sources (lakes, rivers, and wetlands), semi-permanent sources (dry channels, creeks, lagoons, and waterholes), and man-made sources (dams, artificial lakes, canals, artificial ponds, and swamps) (DENR, 2020). Because dissolved salts raise the bulk of water more than the volume, seawater is denser than pure water and freshwater. Seawater pH is normally between 7.7 and 8.4. Sea water is extremely saline (salt concentration of around 35 g/L), making it unsuitable for direct human consumption, but it is used for a variety of purposes despite accounting for 97% of earth's water. Groundwater is a valuable freshwater resource that accounts for roughly two-thirds of the world's freshwater reserves (Chilton 1992). Groundwater utilization as a source for domestic, municipal,

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agricultural, and industrial operations continues to rise, owing mostly to the continued development of surface water through dams in developing nations (Sangodoyin & Agbawhe, 1991). The quality of ground and surface water sources must be assessed on a continuous basis.

In the USA, the Safe Drinking Water Act (SDWA) establishes maximum contamination levels (MCLs) for several heavy metals in drinking water, such as lead, arsenic, and mercury. These standards must be met by public water systems. The WHO issues guidelines and health-based values for heavy metal content in drinking water to help guide international efforts to provide safe drinking water (WHO, 1995). The Environmental Protection Agency (EPA) monitors and controls heavy metal contamination in water sources, as well as conducting research and providing advise on water quality issues. The maximum allowable limits for heavy metals, as well as concentrations accepted by various international bodies, are utilized as global standards around the world. The two organizations taken into consideration are WHO and the National Agency for Food and Drug Administration and Control (NAFDAC) of Nigeria.

Table 1: Acceptable ranges of heavy metals in drinking water (Garbarino *et al*., 1995)

Heavy Metals	Maximum concentration (WHO: mg/L)	Maximum concentration (NAFDAC: mg/L
Zinc	5.000	5.00
Arsenic	0.010	0.00
Magnesium	50.00	30.0
Calcium	50.00	50.0
Cadmium	0.003	0.00
Lead	0.010	0.00
Silver	0.000	0.00

Water contamination occurs when it is contaminated by solid, human, and animal activity, chemical industry effluents, and dissolved gasses (Jimoh and Umar, 2015). Metal levels in the environment, including air, water, and soil, are rising in some circumstances, thanks to a variety of commercial and home sources (Punitha and Selvarajan, 2018). The most prevalent form of contaminant is heavy metals (with relatively high densities [>5 g/cm3], atomic weights, and atomic numbers), which are employed as environmental monitoring standards (Duffus, 2002; Duruibe *et al*., 2002). They are produced by chemical leaching of bedrock, the discharge of urban, industrial, and rural wastes, and water drainage (Xie, 2022). Increased urbanization and industrialization are to blame for elevated levels of trace metals, particularly heavy metals, in our rivers (Seema *et al*., 2011). Urbanization generally increases phosphorus concentrations in urban catchments (Paul *et al*., 2001). Heavy metals have a significant impact on aquatic flora and wildlife, which then enter the food chain and eventually affect humans. Some compounds, such as cyanide, thiocyanides, phenolic compounds, fluorides, and radioactive substances, are toxic to both humans and animals.

Heavy metals have no significant beneficial effects in the body (Witkowska *et al*., 2021). These heavy metals can be found in industrial waste near a freshwater body, smoke from motor exhaust, nuclear waste, plastics, rusted metals, metallic ores from the earth, refineries, improper waste disposal, geological processes, petroleum effluent, and so on (Mamta & Dhriti, 2021; Onyeukwu *et al*., 2023). They are typically found at low concentrations yet enough to cause damage in water supplies. These heavy metals can accumulate in bodily tissues and pass the blood-brain barrier, damaging the heart, digestive system, neurons, and red blood cells, leading to anemia, as well as adenosine-triphosphate (ATP) production in cells (Witkowska *et al*., 2021). They can also influence proteins that aid in development and cell division, among other things (Duruibe *et al*., 2002). As a result of these accumulations, they produce a large number of free radicals that enhance oxidation in the body, increasing the risk of chronic health conditions such as cancer, kidney failure, neurological disorders, abnormal red blood cell formation, heart failure, and birth defects (Briffa *et al*., 2020). These negative events typically occur when they exceed their legal limit (Miediegha and Bunu, 2020).

Heavy metals like lead, arsenic, mercury, and cadmium are well-documented as harmful when consumed. Long-term exposure to even low levels of these pollutants in drinking water can cause major health problems such as cancer, renal dysfunction, neurological damage, and developmental disorders, especially in children (Balali-Mood *et al*., 2021). Investigation and monitoring of heavy metal levels in drinking water is critical for public health and safety (WHO, 2011). Heavy metals dumped into water bodies damage both human health and aquatic ecosystems (Mengistu, 2021). These toxins can build up in aquatic organisms, disrupting food networks and harming biodiversity. Understanding the environmental impacts of heavy metal contamination is critical to ecosystem conservation and restoration. Governments and environmental organizations throughout the world have set laws and standards to restrict the quantity of heavy metals in drinking water (WHO, 2011). According to the WHO, the most common heavy metals in water that cause public health concerns are cadmium, manganese, arsenic, lead, and copper. When bound to enzymes such as DNA polymerase, RNA polymerase, glutathione synthase, and others that require specific cofactors to function properly, they can operate as non-competitive inhibitors (Ravindra *et al*., 2014). Although long-term exposure to vanadium has no recorded deleterious impact on health; changes detected were within the range of normal values in every case (Kucera *et al*., 1992; Lener *et al*., 1998). Atomic Absorption Spectrophotometry (AAS), among other methods, has been used to determine the level of heavy metals in food and pharmaceuticals (Bunu *et al*., 2023a, Bunu *et al*, 2023b). The study aims to quantify the level of heavy metal in the drinking water of public primary school children obtained from their water bottles in selected schools from three Local Government Areas (Uyo, Abak, and Itu) in Akwa Ibom State of Nigeria.

METHOD

Study Site and Sample Collection

This research was carried out in Akwa Ibom State: located in the South-South geopolitical zone in Nigeria. Akwa Ibom State lies geographically between Latitude 5° 00'N and 7° 50'E. The State consists of 31 Local Government Areas. **S**eventy-five water samples were obtained from the pupils drinking water bottles from three public primary schools in each Local Government Area namely; St. Joseph Primary School, Uyo (L1), Government School Ediene II, Abak (L2), and Government School Ibiaku Itam II, Itu (L3). Five water samples were obtained from each class which amounted to twenty-five water samples from each school. Each sample bottle used to collect the water from the pupil in each class was labeled P1, P2, P3, P4, and P5 for Primary 1, 2, 3, 4, and 5, respectively.

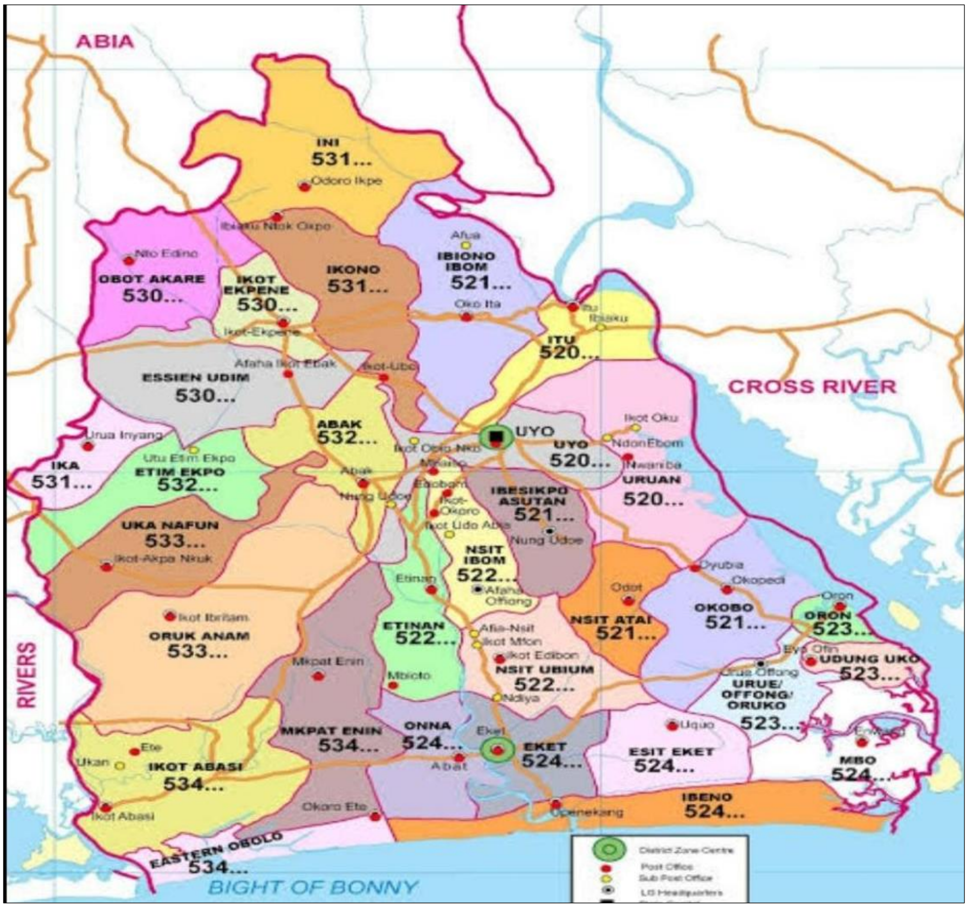

Figure 1: Map of Akwa Ibom State showing Local Government Areas

Sample Preparation

Exactly 100 mL of sample water was collected and placed into well-labeled beakers, one for each sample container used to collect the water sample from the school. The beakers were then brought to the fume cupboard's heating mantle, where 0.5 mL of concentrated nitric acid was measured and applied to eliminate contaminants, resulting in a pure sample (Lavanya *et al*., 2021). Each beaker containing the sample water and acid was then heated in a heating mantle for two hours to guarantee proper digestion and contaminants were freed by dissolving their bindings, ensuring total removal during filtration. The heating mantle was set to 100 volts to ensure that the sample water in the beaker evaporated from 100 mL to 20 mL while in the fume cupboard. To prevent contamination, each beaker's water sample was filtered into a 100 mL volumetric flask with a new filter paper and funnel (rinsed with distilled water before use). Following each filtering into the volumetric flask, the filter paper was washed with distilled water. The volumetric flask was then filled with distilled water up to 100 mL capacity. The filter paper was discarded following usage (Lavanya *et al*., 2021).

Atomic absorption spectroscopy

The sample water in the volumetric flask was then transferred to well-rinsed and clean well-labeled small containers and inserted into the Atomic Absorption Spectrophotometer. Calibrated solutions of the target metal ions were prepared from the standard stock by serial dilution. A calibration curve for each metal was prepared by plotting the absorbance of standards against their concentration.

RESULT

Heavy metals Level mean concentrations

The result at L1 indicates that there was no significant difference ($p<0.05$) between the mean concentrations of heavy metals for P2 and P3, while these two mean concentrations were significantly higher than the mean concentrations of heavy metals for P1, P4, and P5. The level of Lead was highest in P2, Cadmium level was highest in P2 and there was no significant difference in arsenic levels from P1 to P5. iron level was highest in P4 and there was no significant difference in vanadium levels between the classes for P1 to P5. For L2, it showed that the mean concentrations of iron for P1 and P5 are significantly different from each other but both are not significantly different from the mean concentrations for P2 and P4. The level of lead was highest in P5, cadmium level was highest in P1 and there was no significant difference in arsenic levels for P1 to P5. The iron level was highest in P5 and the level of Vanadium was highest in P1. The result from L3 indicates that the mean concentrations of Arsenic for P2 and P3 are not significantly different from each other but are different from the mean concentration for P1. The level of Lead was highest in P3, the Cadmium level was highest in P1, and the Arsenic level was highest in P1. The level of Iron was highest in P1 and there was no significant difference in Vanadium levels from P1 to P5.

Table 2: The mean concentrations of heavy metals obtained from the water samples from all locations

Study Locations	Sample ID	Lead	Cadmium	Arsenic	Iron	Vanadium
L1	P1	0.0206^{a} ±0.177	0.008^{a} ±0.002	0.001^{a} ±0.000	0.119^{a} ±0.012	0.001 ±0.000
	P2	2.422^{b} ±0.434	0.011^{a} ±0.005	0.001^{a} ±0.000	0.927^{b} ±0.062	0.001 ±0.000
	P3	2.256^{b} ±0.490	0.007^{a} ±0.002	0.001^{a} ±0.000	0.396^{a} ±0.173	0.001 ±0.000
	P4	0.323^{a} ±0.099	0.051^{b} ±0.007	0.001^{a} ±0.000	0.988^{b} ±0.030	0.001 ±0.000
	P5	0.840^{a} ±0.357	0.007^{a} ±0.001	0.001^{a} ±0.000	0.379^{a} ±0.066	0.001 ±0.000
L2	P 1	0.754^{a} ±0.345	0.014^{ab} ±0.003	0.001^{a} ±0.000	0.408^{a} ±0.052	0.007^{a} ±0.003
	P 2	1.044^{a} ±0.259	0.005^{a} ±0.002	0.001^{a} ±0.000	1.093^{ab} ±0.174	0.002^{a} ±0.000
	P 3	0.474^{a} ±0.136	0.024^{b} ±0.004	0.001^{a} ±0.000	0.674^{a} ±0.089	0.007^{a} ±0.003
	P 4	1.563^{a} ±0.259	0.021^{ab} ±0.001	0.001^{a} ±0.000	1.037^{ab} ±0.038	0.001^{a} ±0.000
	P 5	7.126^{b} ±2.305	0.014^{ab} ±0.005	0.001^{a} ±0.000	2.930^{b} ±1.103	0.002^{a} ±0.000
L3	P 1	4.901^{a} ±1.604	0.018^{a} ±0.006	0.011^{b} ±0.004	1.193^{a} ±0.591	0.001^{a} ±0.000
	P 2	3.746^{a} ±2.861	0.013^{a} ±0.005	0.001^{a} ±0.000	0.443^{a} ±0.344	0.001^{a} ±0.000
	P 3	8.303^{a} ±1.615	0.013^{a} ±0.002	0.001^{a} ±0.000	0.147^{a} ±0.051	0.001^{a} ±0.000
	P 4	1.771^{a} ±0.690	0.009^{a} ±0.001	0.002^{a} ±0.000	1.126^{a} ±0.149	0.001^{a} ±0.000
	P 5	1.826^{a} ±0.647	0.008^{a} ±0.001	0.001^{a} ±0.000	0.572^{a} ±0.055	0.001^{a} ±0.000

Values are expressed as mean ±S EM (n = 5); significant at $p < 0.05$, P1 = primary 1(one); Means using the same superscript (^{a} or ^{b}) along the column are not significantly different from each other while means with different superscripts are significantly different from other means. For L1 example, the mean of P3 for lead is significantly different from the mean for P1, P4, and P5 but is not significantly different from the mean for P2. For L2; although the mean concentration of iron for P1 is significantly different from the mean concentration for P5, it is not significantly different from the mean concentration for P2 and P4. Hence, the mean concentration for P5 is significantly higher than the mean concentration for P1. L3 indicates that the mean concentration of Arsenic for P2 and P3 are not significantly different from each other but are significantly different from the mean concentration for P1.

Exposure and health risk assessment

To assess both non-cancer and cancer risks for these school children, the Estimated Daily Intake (EDI) of heavy metals is used to quantify the oral exposure dosage of substances i.e. heavy metals (Bamuwuwamye *et al*., 2017). The EDI of the Heavy Metals (HMs) via oral ingestion was calculated using Equation (1);

$$EDI = \frac{C\ x\ IR\ x\ ED\ x\ EF}{BW\ x\ AT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad \text{Eqn (1)}$$

EDI = Estimated Daily Intake (mg/kg/day); C = concentration of the contaminant in the water sample (mg/L); IR = Ingestion Rate per unit time (1 L/day for a child and 2.2 L/day for an adult); ED = Exposure Duration to heavy metals was assumed to be equivalent to the average life expectancy for Nigeria (55.8 years); EF = Exposure Frequency for children which is 365 days; AT = Average Exposure Time for non-cancer risk which is 55.8 x 365 = 20,294 days.

The growth charts created by the Centers for Disease Control and Prevention (CDC) were used to estimate the body weight of children based on their age. Furthermore, the ages of the children and their associated classes from primary one to primary five were calculated. According to USEPA IRIS, the oral reference doses for lead, cadmium, arsenic, iron, and vanadium are 0.00036, 0.0005, 0.0003, 0.007, and 0.001 mg/kg/day (USEPA, 2011). The EDI of arsenic for the students from L1, L2, and L3 was below the standard dose (0.0003 mg/kg/day) from P1 to P5 in the three schools.

Table 3: Estimated Daily Intake of heavy metals from the study locations

Heavy Metal	Sample ID	Age range (years)	Body weight (Kg)	L1 EDI	L2 EDI	L3 EDI
Arsenic	P1	4 - 5	22.00	0.00004	0.00004	0.00004
	P2	6 - 7	28.22	0.00003	0.00003	0.00003
	P3	8 - 9	36. 47	0.00002	0.00002	0.00002
	P4	10 - 11	45.88	0.00002	0.00002	0.00002
	P5	11 - 12	57. 64	0.00001	0.00001	0.00001
Cadmium	P 1	4 - 5	22.00	0.0003	0.0006	0.0008
	P 2	6 - 7	28.22	0.0004	0.0001	0.0004
	P 3	8 - 9	36. 47	0.0001	0.0006	0.0003
	P 4	10 - 11	45.88	0.0011	0.0004	0.0001
	P 5	11 - 12	57. 64	0.0001	0.0002	0.0001
Iron	P 1	4 - 5	22.00	0.0054	0.0186	0.0544
	P 2	6 - 7	28.22	0.0042	0.0388	0.0157
	P 3	8 - 9	36. 47	0.0108	0.0018	0.0040
	P 4	10 - 11	45.88	0.0216	0.0226	0.0246
	P 5	11 - 12	57. 64	0.0065	0.0510	0.0099
Lead	P 1	4 - 5	22.00	0.0009	0.0343	0.2235
	P 2	6 - 7	28.22	0.0861	0.0371	0.1332
	P 3	8 - 9	36. 47	0.0620	0.0130	0.2284
	P 4	10 - 11	45.88	0.0070	0.0341	0.0387
	P 5	11 - 12	57. 64	0.0146	0.1240	0.0317
Vanadium	P 1	4 - 5	22.00	0.00004	0.0003	0.00004
	P 2	6 - 7	28.22	0.00003	0.00007	0.00003
	P 3	8 - 9	36. 47	0.00002	0.0001	0.00002
	P 4	10 - 11	45.88	0.00002	0.00002	0.00002
	P 5	11 - 12	57. 64	0.00001	0.00003	0.00001

The EDI of Cadmium is below the reference dose (0.0005 mg/kg/day) for P1 to P5 except for Primary four which is significantly above the reference dose for L1. The EDI values of Cadmium for P1 and P3 were above the reference dose (0.0005 mg/kg/day) but those of P2, P4, and P5 are below the reference dose, for L2 The EDI values of Cadmium for P1 were above the reference dose (0.0005 mg/kg/day) but those of P2, P3, P4, and P5 were below the reference dose, for L3. The EDI of iron for P3 and P4 are significantly above the reference dose (0.007 mg/kg/day) but those of P1, P2, and P5 are below the reference dose for L1, while at L2, the EDI values for P1, P2, P4, and P5 were above the reference dose (0.007 mg/kg/day) but that of P3 was below the reference dose. The EDI values of Iron for P1, P2, P4, and P5 are above the reference dose (0.007 mg/kg/day) except for P3 at L3. The EDI of lead was significantly above the reference dose (0.00036 mg/kg/day) for P1 to P5 at all study locations (L1 - L3). Vanadium EDI was below the reference dose (0.001 mg/kg/day) for all classes across the study locations (L1 – L3).

Target Hazard Quotient

The Target Hazard Quotient was used to evaluate the non-carcinogenic risk associated with the ingestion of heavy metals found in the water sample. This was determined by calculating the ratio of potential exposure to the substance dose in comparison to the reference dose at which no adverse effects are expected. The non-cancer hazard quotient, as stated in Equation 2, was used to calculate the non-cancer risk of heavy metals in drinking water from these children's water bottles.

$$HQ = \frac{EDI}{RfD} \text{ ……………………………….. Eqn (2)}$$

HQ = non-cancer hazard quotient; EDI = chronic daily intake (mg metal/ kg/day); and RfD = oral reference dose, that approximates the human population daily oral exposure level. This gives an estimation of the daily tolerable exposure of persons to the metal without being exposed to any significant risk or harmful effect during a lifetime (Wei *et al*., 2020). The Estimated Hazard Index (EDI), which is the total of all hazard quotients determined for each heavy metal, was used to assess the potential danger to human health from numerous heavy metal exposures (Li *et al*., 2013). A value of HQ or HI < 1 indicates no substantial non-cancer risk. A value of HQ or HI ≥ 1 indicates significant non-cancer risk, which increases with increasing HQ or HI (Wei *et al*., 2015).

Hazard index (HI)

The hazard index assesses the overall non-carcinogenic harm to human health from exposure to more than one heavy metal. Exposure to more than one heavy metal may produce a cumulative effect. HI is the total of the Lead, Cadmium, Arsenic, Iron, and Vanadium Hazard Quotient for Children (Adefa and Tefara, 2020). L1 results showed THI values (0.2211) for Arsenic, Cadmium, Iron, Lead, and Vanadium were substantially less than 1 (<1). The THI values (0.3777) for arsenic, cadmium, iron, lead, and vanadium were much lower than 1 (<1) for L2. The THI value (0.7658) for arsenic, cadmium, iron, lead, and vanadium was less than one (<1) for L3.

Table 4: Hazard Quotient and Total Hazard Index for Heavy Metals in L1

Study Location	Sample ID	Arsenic	Cadmium	Iron	Lead	Vanadium	Total HI
L1	P 1	0.00004	0.0003	0.0054	0.0009	0.00004	0.0066
	P 2	0.00003	0.0004	0.0042	0.0861	0.00003	0.0907
	P 3	0.00002	0.0001	0.0108	0.0620	0.00002	0.0729
	P 4	0.00002	0.0011	0.0216	0.0070	0.00002	0.0297
	P 5	0.00001	0.0001	0.0065	0.0146	0.00001	0.0212
							Σ THI = 0.2211
L2	P 1	0.00004	0.0006	0.0186	0.0343	0.0003	0.0538
	P 2	0.00003	0.0001	0.0388	0.0371	0.00007	0.0761
	P 3	0.00002	0.0006	0.0018	0.0130	0.0001	0.0155
	P 4	0.00002	0.0004	0.0226	0.0341	0.00002	0.0571
	P 5	0.00001	0.0002	0.0510	0.1240	0.00003	0.1752
							Σ THI = 0.3777
L3	P 1	0.00004	0.0008	0.0544	0.2235	0.00004	0.2787
	P 2	0.00003	0.0004	0.0157	0.1332	0.00003	0.1493
	P 3	0.00002	0.0003	0.0040	0.2284	0.00002	0.2327
	P 4	0.00002	0.0001	0.0246	0.0387	0.00002	0.0634
	P 5	0.00001	0.0001	0.0099	0.0317	0.00001	0.0417
							Σ THI = 0.7658

Cancer risk

Cancer risk is the danger associated with a lifetime average dose of 1 mg/kg body weight per day of a pollutant. Cancer risk is measured in terms of Incremental Lifetime Cancer Risk (ILCR), which is the probability of developing cancer over a 70-year period as a result of a 24-hour exposure to a probable carcinogen (Adamu *et al*., 2014). Cancer risk was computed as the product of EDI mg/kg/day and Cancer slope factor (CSF) measured in mg/kg/day^{-1}, as stated in Equation 3 (Adamu *et al*., 2015).

$ILCR = EDI\ x\ CSF$ …………….. Eqn (3)

ILCR = Incremental Life Cancer Risk; EDI = Estimated daily intake (mg/kg/BW/day); CSF = Cancer slope factor of each heavy metal is the risk generated by a lifetime average amount of one of carcinogen chemical and is contaminant-specific (Mohammadi *et al*., 2019). The following are the Cancer slope of heavy metals used in this study for the calculation of the ILCR; Arsenic; 0.15x10^{-1}, Cadmium; Not Available (NA), Iron; NA, Lead 8.5x10^{-3}, Vanadium; NA. Source: Integrated Risk Information System (USEPA, 2011). The sum of each metal incremental risk (Σ ILCR) was used to calculate the overall cancer risk associated with consuming a specific type of water and exposure to numerous pollutants. The USEPA defines the minimum or acceptable risk for regulatory purposes as 1x10-6 to 1x10-4 (Li *et al*., 2012). The total cancer risk for all heavy metals from all regions (L1-L3) was under the allowable limit set by the USEPA in 2011.

Table 5: Total Cancer Risk of Heavy Metals in Study Locations

Study Location	Sample ID	Arsenic	Cadmium	Iron	Lead	Vanadium	Total Cancer Risk
L1	P 1	$6x10^{-5}$	$1.5x10^{-4}$	NA	$6.5x10^{-7}$	NA	$6.5x10^{-7}$
	P 2	$5.4x10^{-5}$	$2x10^{-4}$	NA	$8.5x10^{-7}$	NA	$8.5x10^{-7}$
	P 3	$3x10^{-5}$	$5x10^{-5}$	NA	$2.7x10^{-5}$	NA	$7x10^{-6}$
	P 4	$3x10^{-5}$	$5.5x10^{-4}$	NA	$9.5x10^{-6}$	NA	$9.5x10^{-6}$
	P 5	$1.5x10^{-5}$	$5x10^{-5}$	NA	$4.1x10^{-6}$	NA	$9.1x10^{-6}$
L2	P 1	$6x10^{-5}$	$3x10^{-4}$	NA	$6.9x10^{-7}$	NA	$6.9x10^{-7}$
	P 2	$5.4x10^{-5}$	$5x10^{-5}$	NA	$9.3x10^{-7}$	NA	$9.3x10^{-7}$
	P 3	$3x10^{-5}$	$1.5x10^{-4}$	NA	$7.9x10^{-7}$	NA	$7.9x10^{-7}$
	P 4	$3x10^{-5}$	$2x10^{-4}$	NA	$3x10^{-8}$	NA	$3x10^{-8}$
	P 5	$1.5x10^{-5}$	$1x10^{-4}$	NA	$9.2x10^{-6}$	NA	$4.2x10^{-6}$

Study Location	Sample ID	Arsenic	Cadmium	Iron	Lead	Vanadium	Total Cancer Risk
L3	P 1	$6x10^{-5}$	$4x10^{-4}$	NA	$7.5x10^{-7}$	NA	$7.5x10^{-7}$
	P 2	$5.4x10^{-5}$	$2x10^{-4}$	NA	$6.5x10^{-7}$	NA	$6.5x10^{-7}$
	P 3	$3x10^{-5}$	$1.5x10^{-4}$	NA	$7.2x10^{-7}$	NA	$7.2x10^{-7}$
	P 4	$3x10^{-5}$	$5x10^{-5}$	NA	$2.1x10^{-7}$	NA	$2.1x10^{-7}$
	P 5	$1.5x10^{-5}$	$5x10^{-5}$	NA	$1.1x10^{-7}$	NA	$1.1x10^{-7}$

NA: Not Available

DISCUSSION

Heavy metals (arsenic, cadmium, iron, lead, and vanadium) were found and measured in the drinking water of public primary school students, specifically in their water bottles in L1, L2, and L3. It was observed that in all three selected schools, the mean concentrations of Lead from P1 to P5 exceeded the permissible limit of 0.01 mg/L (WHO, 2011) and 0.00 mg/L (NAFDAC), as well as the mean concentration of Cadmium from P1 to P5 and for Iron; the WHO states that the values of Iron up to 2 mg/L do not present a hazard to health and concentrations between 1-3 mg/L can be acceptable for people drinking anaerobic well-water (WHO, 1996). The mean amounts of arsenic and vanadium were generally below the permitted level. Previous research has found that lead levels in several water sources ranged from 0.10 mg/L to 0.37 mg/L, which exceeded the allowable limit of 0.01 mg/L. Furthermore, the mean Cadmium content ranged between 0.10 mg/L and 0.35 mg/L, which was significantly higher than the allowed limit (Emmanuel *et al*., 2022). Hence, the result from this study showed that the range of Lead for L1 was from 0.0206 mg/L to 2.256 mg/L, for L2, the range was 0.754 mg/L to 7.126 mg/L and for L3, the range was 1.771 mg/L to 8.303 mg/L. For Cadmium, L1, ranged from 0.007 mg/L to 0.051 mg/L, L2, ranged from 0.005 mg/L to 0.024 mg/L, L3, 0.008 mg/L to 0.018 mg/L. This shows significantly high levels of Lead and Cadmium which might be a result of industrial activities, road construction, improper disposal of electronic parts, batteries, metals, etc, this can leach into various water sources where the children get water for the school.

The EDI for Lead in L1, from P1 to P5 significantly exceeded the reference dose (0.00036 mg/kg/day), the highest value emerged from P2 at 0.0620 mg/kg/day. The EDI for Cadmium were all below the reference dose (0.0005 mg/kg/day) except from P4. The highest value emerged from P4 at 0.0011 mg/kg/day. For Iron, the EDI values were above the reference dose (0.007 mg/kg/day) except P1, P2, and P5 were below. Arsenic and Vanadium were below the reference dose (0.0003 mg/kg/day) and 0.001 mg/kg/day. In L2, the EDI for Cadmium in P1, P3, and P4 were above the reference dose while P2 and five were below the reference dose. The EDI for Iron was above the reference dose except for P3 0.0018 mg/kg/day. The EDI for Lead from P1 to P5 was above the reference dose. Arsenic and Vanadium were below the reference dose. At L3, the EDI for Cadmium was all below the reference dose except from P1, where the highest value emerged from P2 0.0008 mg/kg/day. For Iron, the EDI values were above the reference dose from P1 to P5. For Lead, the EDI values were above the reference dose from P1 to P5. Arsenic and Vanadium were below the reference dose from P1 to P5. The Chronic Daily Intake values were in the order of Cadmium followed by Mercury and then Lead, from highest to least from the previous report (Emmanuel *et al*., 2022). In this study, L1 was in the order Lead, Iron, Cadmium, Arsenic, and Vanadium. The same trend occurred for L2 and L3.

The Hazard Index (HI) for the heavy metals (summation of the hazard quotient of each heavy metal) in the three selected schools followed a trend from highest to lowest, although, none of the values were greater or equal to one (≧ 1). Based on the schools from highest to lowest, the Total Hazard Index (ΣTHI) was highest in L3 (0.7658), followed by L2(0.3777), and least in L1 (0.2211). An HI value of 1 < HI < 5 suggests a level of concern (Li *et al*., 2013). Lead reported was to be a major contributor to non-cancer risk (Bamuwuwamye *et al*., 2015). Hence, the hazard indices for the children were not up to one to indicate a non-cancer risk, therefore there is no significant health risk posed to these children.

The results of the Cancer risk due to heavy metal exposure in their drinking water show the Incremental Life Cancer Risk (ILCR) via oral digestion in children. For L1, Arsenic and Cadmium values from P1 to 5P were within the range, the highest value for Arsenic was ($6x10^{-5}$) and for Cadmium was ($5.5x10^{-4}$) which was within the permissible limit. Iron and Vanadium were Not Available (no established cancer slope factor). Lead was relatively below the acceptable range of 10^{-4} to 10^{-6} (USEPA, 2011; Li *et al*., 2013) in the three selected schools. In L2, Arsenic and Cadmium values from Primary one to five were within the range, the highest value for Arsenic was ($6x10^{-5}$) and for Cadmium was ($3x10^{-4}$). Lead was relatively below the acceptable range. At L3 Arsenic and Cadmium values from P1 to P5 were within the permissible range, the highest value for Arsenic was ($6x10^{-5}$) and for Cadmium was ($4x10^{-4}$). Lead was relatively below the acceptable range. However, the Total Cancer Risk (Σ TCR) from the three schools showed the values were significantly below the permissible range, hence there is low cancer risk among the children.

CONCLUSION

The study found that the water samples from these primary school children's drinking water bottles contained significantly higher concentrations of lead, iron, and cadmium than the permitted limit from three selected schools across three LGAs in Akwa Ibom State, Nigeria. The Hazard Index for heavy metals in three schools was less than one, indicating no non-cancer risk. The Total Cancer risk was also below acceptable ranges, indicating a low cancer risk among schoolchildren. However, measures should be taken to reduce heavy metal concentrations in the water consumed in these locations.

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