Heavy Metal Contamination and Health Risk Assessment of Groundwater Sources to Waste Dumpsites in Port Harcourt

[1]Alaye A.S. Bibiye [2]David N. Ogbonna [3]Sodienye A. Abere [4]Augusta. Ayotamuno

[1,4.] Institute of Geo-Science and Environmental Management, Rivers State University

[2.] Faculty of Science, Department of Microbiology, Rivers State University

[3.] Faculty of Agriculture, Department of Forestry and Environmental Toxicology, Rivers State University

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ABSTRACT: *Heavy metal contamination and health risk assessment of groundwater ingestion in proximal relation to waste dumpsites in Port Harcourt were investigated during the rainy and dry season of 2020. Five (5) sampling points were established and designated as Groundwater (GW) as follows: GW1, GW2, GW3, GW4, and GW5 respectively. The control station used was GW5. Nine (9) heavy metals (Cd, As, Mn, Cu, Hg, Ni, Fe, Pb, and Zn) were assessed during the period using an atomic absorption spectrometer and were compared with National Standard for Drinking Water Quality (NSDWQ) of Nigeria. The Estimated Daily Intakes of Metal (EDIM) of these metals for adult males, females, and children revealed no significant health issues during the wet and dry seasons. However, the Health Risk Index (HRI) for non-carcinogenic revealed that during the wet season Pb in the control station (GW5) had a concentration of 4.000E+0 mg/kg/day that was far higher than unity (HRI<1) for females. The Arsenic (As) values for children at GW1, 2, and 3 were also higher than unity. The pollution index for each heavy metal across sample location showed that Fe in GW1 and 3 during the dry season was high while in the wet season, values for Cu in GW4 was very high, Fe in GW1 and 2, and Mn in GW2 were higher than the unity. The overall pollution index of the heavy metal studied revealed that only Fe exceeded the unity value during the dry season whereas Cu, Fe, Pb, and Mn concentrations were also higher during the wet season. This calls for concern considering the vulnerability of children and women who may have been exposed to groundwater sources via ingestion. The heavy metal contamination as observed in this study may have occurred due to anthropogenic activities superimposed by the unregulated insanitary waste disposal phenomenon.*

KEYWORDS: groundwater, waste management, heavy metal, pollution index, health risk assessment.

INTRODUCTION

Water is life and composed of hydrogen and oxygen molecules chemically combined in the ratio of 2:1. According to the US National Academies of Sciences, Engineering and Medicine, 15.5

cups (3.7 litters) for men and 11.5 (2.7 litters) for women's daily fluid intake are adequate for an average, healthy adult living in a temperate climate. Albeit, consuming too much water is harmful to the body. In line with the Millennium Development Goal (MDG) for water for people, Sustainable Development Goals (SDG) six (6) ensures availability and sustainable management of water and sanitation for all. Water should be available (be in abundance), accessible (reachable to end-users always), affordable (the least or poorest person should have the purchasing power), and acceptable (quality i.e., free from all contaminants) [1]. Groundwater like springs wells and boreholes have been a good source of drinking water to humans. However, industrial, agricultural, municipal wastes among others when improperly managed interfere with soil, water (ground and surface), and air quality [2, 3] and this may affect the health of the individual, community or the populace been exposed to it [4]. In 2015, MDG proposed 75% reduction of solid waste in cities in a bid to ensure the health and environmental safety [5].

A country's economy lies on industrialization via the established plants and factories [6], however, the by-products discharged from these plants and factories are unhelpful to the environment [3] since their contamination potential is inevitable mostly in a developing country. This is because their effluents are not safely treated due to the paucity of waste management infrastructure [7] and rareness of highly efficient and economic treatment technology [6], and failures in monitoring and control by the relevant institution(s). More so, in an industrial hub like Port Harcourt where there is daily massing of people into the city, it is expected that there will be an increase generation of municipal, industrial, agricultural, domestic waste among others. This underscores the need for an effective waste management practice at all levels in a bid to cushioning their resultant impacts on both man and the environment [8, 9, 10, 11].

Heavy metals are a group of metals and metalloids that have relatively high density and are toxic even at part per billion (ppb) levels. These groups of metals have an atomic density greater than 5 gcm^{-3}. E.g., Lead (Pb), Arsenic (As), Mercury (Hg), Zinc (Zn), Copper (Cu), Cadmium (Cd), Nickel (Ni), Chromium (Cr), Iron (Fe) just to mention but these, and they could occur either by natural or anthropogenic means [12, 13]. Some of these heavy metals are highly indispensable in the biochemical processes in living organisms but when they become excess and exceed the normal concentration level, they become detrimental to the organism [14, 15]. It has been observed that heavy metal pollution has become one of the foremost worries of human beings since it is associated with hidden, persistent, and irreversible variables [16, 17]. Thus, the dearth of quality or wholesome water may become inevitable in Port Harcourt and its environs. This may exert disequilibrium in the demand and supply chain of water as a commodity. This may likely influence the social life of the people in addition to various health problems associated with it [18].

The determination of heavy metal pollution in the water can be carried out by measuring the concentration value [18] of each metal and compared to the standard set by the World Health Organization (WHO), US Environmental Protection Agency (US EPA), or the [20]- National Drinking Water Quality Standard.

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In Port Harcourt, several waste dumpsites are traversing from Obio/Akpor to Ikwerre Local Government Areas including that of Oyigbo Local Government Area. Initially, these sites were sited a little far of living premises but due to urbanization; most of those sites have become proximal to residential areas. This situation has become precarious in all respect and demand environmental checks via groundwater quality testing and its likes as residents sink boreholes without recourse to environmental and public health standards. Leachate(s) from waste dump sites can interfere with groundwater quality and runoff from dumpsite could also influence surface water bodies [7, 21, 22, 23]. Therefore, this study was aimed at evaluating heavy metal contamination and health risk assessment of groundwater in proximal relation to waste dumpsites in Port Harcourt.

METHODOLOGY

Study Area

Port Harcourt has a geographical coordinate of latitude and longitude: 4.824167 and 7.03361, with Degree Minute and Second (DMS) (Lat. $4^{o}49^{/}27.0012^{//}$N and Long. $7^{o}2^{/}0.9996^{//}$E, respectively and lies 9 meters above sea level with a tropical climate. It has a significant rainfall pattern in most months of the year with a short dry season that has little effect. The average annual temperature is 26.4ºC or 79.5ºF with precipitation of about 2708 mm or 106.6 inches per year. The most precipitation occurs in September with an average of 141 mm or 16.3 inches. The driest month is January with 36 mm or 1.4inch rainfall. Furthermore, the warmest month of the year occurs in February, with an average temperature of 26.70 ºC or $81.7^{/}$F while August serves as the coldest month, with an average temperature of 25.2ºC or 77.4ºF. Temperature varies by 2.4 ºC or 36.3 ºF throughout the year. The variance in precipitation between the driest month and the wettest month is 378 mm or 15 inches [24].

Collection of Water Samples

Five sample stations were established and designated as GW1, GW2, GW3, GW4, and GWC respectively. GWC was used as the control. Groundwater samples in proximal relation to waste dumpsites were collected for various analyses in clean containers after rinsing the containers with the sample to be collected. The sampling containers were filled to the brim to expel oxygen which could trigger reactions and falsify results. Groundwater samples for heavy metals were preserved with concentrated Nitric acid to pH 2 to prevent the metal ions from forming a precipitate that could adhere to the walls of the sampling containers. While water samples for physicochemical and microbiology analyses were preserved in ice chests or in coolers with ice blocks to inhibit the activity of microbes.

In-Situ Measurements

To maintain the integrity of the samples collected, the fast-changing parameters such as pH, EC, DO, Temperature, BOD, TDS, and Salinity were measured in triplicates and the average was taken and recorded ***in-situ*** using a Portable Digital Multi-Parameters Meter (PDMPM).

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The result was analysed using the single factor ANOVA, and the Turkey Pair-Wise Test in determining the location of the significant difference.

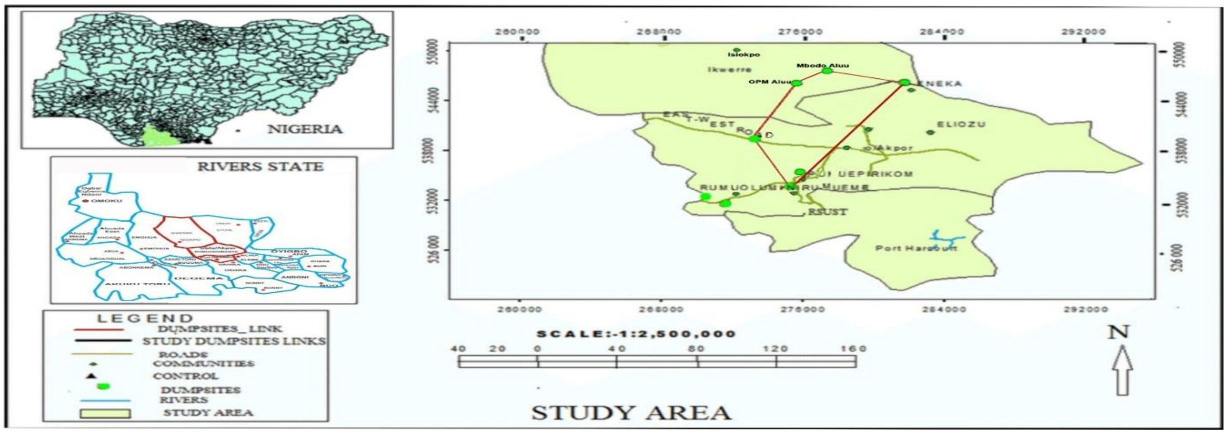

Fig. 1: Map of Rivers State Showing Sample Collection Sites

HEALTH RISK ASSESSMENT

The probable health risk associated with the ingestion of groundwater in proximal relation to waste dumpsites is determined based on Estimated Daily Intake of Metal (EDIM), Health Risk Index, and the Pollution Index (PI):

$$EDI_M = \frac{\text{C metal x C food intake}}{\text{B average}} \tag{1}$$

Where C-metal = Metal concentration in water (mg/L), C food intake = daily intake of water, B-average = the average body weight for adult and children water consumers.

Health Risk Index

The Health Risk Index (HRI) of water was estimated as a ratio of the daily intake of metal to the oral reference dose for each metal. The HRI was computed using the relevant formula:

$$HRI = \frac{EDIM}{RfD} \tag{2}$$

Where EDIM = Estimated Daily Intake of Metal (mg/L), RfD = Oral Reference Dose of metal

Pollution Index

The overall Population Index (PI) status of water was determined by the formula:

$$P1\ water = \sqrt{\frac{Pi\ (average)^2 + Pi\ (Max)^2}{2}} \tag{3}$$

$$Pi = \frac{\text{C metal of each metal}}{\text{US EPA Standard}} \tag{4}$$

RESULT AND DISCUSSION

The estimation of heavy metals exposure level is an essential factor in determining organism health risk. The daily intake of metals (**EDI$_M$**) was intended to averagely estimate the daily heavy metal loading into the body system of specified body weight (70kg) and an average daily intake of 70µg/kg for an adult male, 60kg for an average daily intake of 60kg/kg for an adult female and 15kg for children consumer was assumed in this study (Equation 2). The computed EDIM for the various metals during the dry and wet season in this study is given in Table 1. and 2.

Table 1. Estimated Daily Intake of Metal (EDI$_M$) by Ingestion during the Dry Season (mg/kg/person/day)

Parameter	Gender	GW1	GW2	GW3	GW4	GW5	Remark
Cd	Male	8.571E-6	1.143E-5	5.714E-6	1.143E-5	8.571E-5	EDI<1
	Female	1.000E-5	1.330E-5	6.667E-6	1.333E-5	1.000E-4	EDI<1
	Children	2.000E-5	2.660E-5	1.333E-5	2.667E-5	2.000E-4	EDI<1
Cu	Male	1.143E-5	1.000E-5	1.029E-5	1.057E-5	1.143E-5	EDI<1
	Female	1.333E-5	1.167E-5	1.200E-5	1.233E-5	1.333E-5	EDI<1
	Children	2.667E-5	2.333E-4	2.400E-4	2.476E-4	2.667E-5	EDI<1
Ni	Male	2.229E-4	2.000E-4	1.826E-4	1.571E-4	1.857E-4	EDI<1
	Female	2.600E-4	2.567E-4	2.133E-4	1.833E-4	2.167E-4	EDI<1
	Children	5.200E-4	5.133E-4	4.267E-4	3.667E-4	4.333E-4	EDI<1
Fe	Male	2.028E-2	7.171E-3	1.577E-2	3.314E-3	1.657E-4	EDI<1
	Female	3.207E-2	7.171E-3	1.840E-2	3.687E-3	1.667E-5	EDI<1
	Children	6.413E-2	1.673E-2	3.680E-2	7.733E-3	3.333E-5	EDI<1
Pb	Male	5.715E-5	4.857E-5	5.143E-5	4.571E-5	5.143E-5	EDI<1
	Female	6.667E-5	1.417E-5	6.000E-4	5.333E-5	6.000E-4	EDI<1
	Children	1.333E-4	1.133E-4	1.200E-4	1.067E-4	1.200E-4	EDI<1
Zn	Male	2.000E-4	1.371E-4	1.429E-4	3.143E-4	2.857E-6	EDI<1
	Female	2.333E-4	1.600E-3	1.667E-4	3.667E-4	3.333E-6	EDI<1
	Children	4.667E-4	3.200E-3	3.333E-4	7.333E-4	6.667E-6	EDI<1
Mn	Male	3.429E-4	1.200E-3	5.429E-4	1.086E-3	8.857E-4	EDI<1
	Female	4.000-E-4	1.400E-3	6.333E-4	1.267E-3	1.033E-3	EDI<1
	Children	8.000E-4	2.800E-3	1.267E-3	3.533E-3	2.067E-3	EDI<1
As	Male	1.000E-4	1.029E-4	1.000E-4	1.000E-4	1.171E-4	EDI<1
	Female	1.167E-4	1.200E-4	1.167E-4	1.167E-4	1.367E-4	EDI<1
	Children	2.333E-4	2.400E-4	2.333E-4	2.333E-4	2.733E-4	EDI<1
Hg	Male	2.857E-6	3.143E-6	4.857E-6	3.714E-6	1.143E-6	EDI<1
	Female	3.333E-6	3.667E-6	5.667E-6	4.333E-6	1.333E-6	EDI<1
	Children	6.667E-6	7.333E-6	1.133E-5	8.667E-6	2.667E-6	EDI<1

Source: Author's Field Survey, 2020. GW1=Mile 4 Dumpsite (Apara well 10 Elijiji opposite C Bernett Special Hospital, Rumueme), GW2=Mbodo Aluu Dumpsite off OPM along Tam David-West Airport Road, GW3= Eneka Dumpsite-Rukporkwu Eneka link Road Rumuopu, GW4=RIWAMA Dumpsite Mbodo Aluu before Checkpoint along Tam David-West Airport Road, GW5=Control close to Jephtha Comprehensive School along East-West Road.

The metal concentration (Cd) for adult male during the dry season ranged from 5.7145E-6 to 8.5710E-5 mg/kg/person/day, female ranged from 6.667E-6 to 1.000E-4 mg/kg/person/day, and the children ranged from 1.333E to 2.000E-5 mg/kg/person/day respectively. Copper (Cu) for adult male, female and children ranged from 1.000E-5 to 1.143E-5 mg/kg/person/day, 1.200E-5 to 1.333E-5 mg/kg/person/day, and 2.333 to 2.667 mg/kg/person/day correspondingly. The concentration of Nickel (Ni) for adult male, female and children ranged from 1.571E-4 to 2.229E-4 mg/kg/person/day, 1.833E-4 to 2.600E-4 mg/kg/person/day, and 3.667E-4 to 5.200E-4 mg/kg/person/day. The value of Iron (Fe) for adult male, female and children ranged from1.857E-4 to 2.028E-2mg/kg/person/day, 1.667E-5 to 3.207E-2 mg/kg/person/day and 3.333E-5 to 6.413E-2 mg/kg/person/day (Table 1.). The concentration values of Lead (Pb), Zinc (Zn) and manganese (Mn) for the adult male, female and children in this study ranged from 4.571E-5 to 5.714E-5mg/kg/person/day, 1.417E-5 to 6.667E-5 mg/kg/person/day, 1.067E-4 to 1.333E-4 mg/kg/person/day; 2.857E-6 to 3.143E-4 mg/kg/person/day, 3.333E-6 to 3.667E-4mg/kg/person/day, 6.667E-6 to 7.333E-4 mg/kg/person/day; 0.01089E-4 to 8.857E-4 mg/kg/person/day, 0.0133E-4 to 6.333E-4 mg/kg/person/day, 8.000E-4 to 2.800E-3 mg/kg/person/day while that of the adult male, female and children for Arsenic (As) and mercury (Hg) values ranged from 1.000E-4 to 1.171E-4 mg/kg/person/day, 1.164E to 1.367 mg/kg/person/day, 2.333E to 2.733E mg/kg/person/day; 1.143E-6 to 4.857E-6 mg/kg/person/day, 1.333E to 5.667E-6, and 0.1133E-6 to 8.667E-6 mg/kg/person/day, respectively (Table 1).

However, in the **wet season,** the estimated daily intake (**EDI_M**) values of Cd, Cu and Ni for adult male, female and children ranged from 2.857E-5 to 6.857E-5 mg/kg/person/day, 3.333E-5 to 8.000E-5 mg/kg/person/day, 1.400E-5 to 6.667E-5 mg/kg/person/day; 1.143E-5 to 3.492E-5 mg/kg/person/day, 1.333E-5 to 4.000E-5 mg/kg/person/day, 0.0120E-4 to 5.267 mg/kg/person/day; 1.143E-4 to 3.914E-4, 1.333E-4 to 3.33E-42.667E-48.667E-4, respectively. The values of Fe, Pb and Zn for the adult male, female and children in this study ranged from 1.714E-3 to 8.600E-3mg/kg/person/day, 2.000E-3 to 3.313E-2 mg/kg/person/day, 4.000E-3 to 6.627E-2 mg/kg/person/day; 1.371E-4 to 8.256E-4 mg/kg/person/day, 3.333E-5 to 2.667E-4 mg/kg/person/day, 6.667E-5 to 6.000E-4 mg/kg/person/day; and 4.857E-4 to 7.143E-4 mg/kg/person/day, 5.667E-4 to 8.333E-4 mg/kg/person/day, 1.667E-4 to 1.333E-3 mg/kg/person/day correspondingly (Table 2). Also, the adult concentration value of **EDI_M** for Mn, As, and Hg during the wet season ranged from 6.000E-4 to

Table 2: Estimated Daily Intake of Metal (EDIM) by Ingestion during the Wet Season (mg/kg/person/day)

Parameter	Gender	GW1	GW2	GW3	GW4	GW5	Remark
Cd	Male	2.857E-5	6.000E-5	6.871E-5	6.000E5	6.857E-5	EDI<1
	Female	3.333E-5	7.000E-5	6.667E-5	7.000E5	8.000E-5	EDI<1
	Children	6.667E-5	1.400E-5	1.533E-4	1.400E-4	1.600E-4	EDI<1
Cu	Male	3.429E-5	1.143E-5	5.143E-5	2.229E-4	1.714E-4	EDI<1
	Female	4.000E-5	1.333E-5	6.000E-5	2.600E-4	2.000E-4	EDI<1
	Children	8.000E-5	2.667E-5	1.200E-4	5.200E-4	4.000E-4	EDI<1
Ni	Male	3.914E-4	1.143E-4	1.143E-4	2.000E-4	1.714E-4	EDI<1
	Female	3.333E-4	1.333E-4	1.333E-4	2.333E-4	2.000E-4	EDI<1
	Children	8.667E-4	2.667E-4	2.667E-4	4.667E-4	4.000E-4	EDI<1
Fe	Male	2,840E-2	8.600E-3	1.714E-3	2.314E-3	2.371E-3	EDI<1
	Female	3.313E-2	1.003E-2	2.000E-3	2.700E-3	2.767E-3	EDI<1
	Children	6.627E-2	2.007E-2	4.000E-3	5.400E-3	5.333E-3	EDI<1
Pb	Male	1.714E-4	8.256E-4	2.571E-4	2.857E-5	1.371E-4	EDI<1
	Female	2.000E-4	2.667E-4	3.000E-4	3.333E-5	1.600E-1	EDI<1
	Children	4.000E-4	5.333E-4	6.000E-4	6.667E-5	3.200E-4	EDI<1
Zn	Male	4.857E-4	7.143E-4	5.143E-4	5.457E-4	4.857E-4	EDI<1
	Female	5.667E-4	8.333-E4	6.000E-4	6.367E-4	5.667E-4	EDI<1
	Children	1.133E-3	1.667E-4	1.200E-3	1.273E-3	1.333E-3	EDI<1
Mn	Male	1.171E-3	1.771E-3	6.000E-4	1.343E-3	1.333E-3	EDI<1
	Female	1.367E-3	2.067E-3	7.000E-4	1.567E-3	1.567E-3	EDI<1
	Children	2.733E-3	4.133E-3	1.400E-5	3.133E-3	3.133E-3	EDI<1
As	Male	1.343E-4	1.400E-4	1.457E-4	1.300E-4	1.114E-4	EDI<1
	Female	1.567E-4	1.633E-4	1.753E-4	1.400E-4	1.300E-4	EDI<1
	Children	1.133E-4	3.627E-4	3.400E-4	2.800E-4	2.600E-4	EDI<1
Hg	Male	1.486E-5	1.657E-5	1.400E-5	1.029E-5	9.429E-6	EDI<1
	Female	1.733E-5	1.733E-	1.633E-5	1.200E-5	1.100E-5	EDI<1
	Children	3.467E-5	3.867E-5	3.267E-5	2.400E-5	2.200E-5	EDI<1

Source: Author's Field Survey, 2020. GW1=Mile 4 Dumpsite (Apara well 10 Elijiji opposite C Bernett Special Hospital, Rumueme), GW2=Mbodo Aluu Dumpsite off OPM along Tam David-West Airport Road, GW3= Eneka Dumpsite-Rukporkwu Eneka link Road Rumuopu, GW4=RIWAMA Dumpsite Mbodo Aluu before Checkpoint along Tam David-West Airport Road, GW5=Control close to Jephtha Comprehensive School along East-West Road.

1.771E-3 mg/kg/person/day, 7.000E to 2.067E-3 mg/kg/person/day, 1.400E-5 to 4.133E-3 mg/kg/person/day; 1.114E-4 to 1.457E-4 mg/kg/person/day, 1.300E-4 to 1.753E-4 mg/kg/person/day, 2.600E-4 to 3.400E-4 mg/kg/person/day; and 9.429E-6 to 1.657E-5 mg/kg/person/day, 1.100E-5 to 1.733E-5 mg/kg/person/day, 2.200E-5 to 3.867E-5 mg/kg/person/day, respectively (Table 2).

The obtained values of the expected daily intake of metals (EDI_M) in this study generally were low and lower than the regulatory permissible limit prescribed by [25, 26, 27, 28]. Thus, the result defined that all the EDI_M computed during both seasons was lower than unity as recommended by standards (Table 1 and 2). This means and includes that there is no undue health issue of public health interest that will arise when been exposed to these metals upon consumption. The present result corroborates with that obtained by [29, 30] who carried out similar works in Port Harcourt.

The concentration of Cd, Cu and Ni during the **dry season** for adult male, female and children ranged from 1.142E-2 to 1.700E-1 mg/kg/person/day, 1.330E-2 to 2.000E-1mg/kg/person/day, 2.667E-2 to 5.334E-2 mg/kg/person/day; 2.500E-4 to 2.858E-4 mg/kg/person/day, 2.918E-4 to

3.333E-4 mg/kg/person/day, 0.060E-4 to 6.668E-4; 5.2854 to 1.115E-2 mg/kg/person/day, 6.165E-4 to 1.300E-2 mg/kg/person/day, 1.234E-2 to 2.600E-2 mg/kg/person/day, respectfully. Furthermore, Fe, Pb and Zn had ranged values for adult male, female and children as 2.633E-4 to 2.893E-1 mg/kg/person/day, 2.381E-5 to 4.581E-2 mg/kg/person/day, 4.761E-5 to 9.161E-2 mg/kg/person/ day; 1.214E-2 to 1.286E-1 mg/kg/person/day, 3.354E-3 to 1.500E-1 mg/kg/person/day, 2.668E-2 to 3.333E-2 mg/kg/person; 9.523E-6 to 4.570E-3 m/kg/person/day, 1.111E-3 to 5.333E-3 mg/kg/person/day and 2.222E-5 to 1.067E-2 mg/kg/personal/day, correspondingly. The adult male, female and children concentrated values for Mn, As and Hg ranged from 2.449E-3 to 8.571E-3 mg/kg/person/day, 0.010E-3 to 9.05E-3 mg/kg/person/day, 2.552E-3 to 2.00E-2 mg/kg/person/day; 3.333E-1 to 3.903E-1 mg/kg/person/day, 3.890E-1 to 4.557E-1 mg/kg/person/day, 7.777E-1 to 9.110E-1 mg/kg/person/day, 2.286E-3 to 9.714E-3 mg/kg/person/day, 0.113E-3 to 8.666E-3 mg/kg/person/day, and 5.334E-3 to 2.266E-2 mg/kg/person/day, respectively (Table 3). The HRI computed in this study during the dry season reveals that all the elements were less than **unity** as recommended by standard (**HRI<1**) (Table 3). This simply implied that the consumption of such substance by the public at the rate it has appeared in this study poses no metal toxicity during the dry season.

Table 3: Health Risk Index (HRI) by Ingestion (mg/kg/day) for adult Male, Female, and Children during the Dry Season.

Parameter	Gender	GW1	GW2	GW3	GW4	GW5	Remark
Cd	Male	1.714E-2	2.286E-2	1.142E-2	2.236E-2	1.714E-1	HRI<1
	Female	2.000E-2	2.667E-2	1.333E-2	2.667E-2	2.000E-1	HRI<1
	Children	4.000E-2	5.334E-2	2.667E-2	5.334E-2	4.000E-1	HRI<1
Cu	Male	2.858E-	2.500E-4	2.573E-4	2.643E-4	2.858E-4	HRI<1
	Female	3.333E-4	2.918E-4	3.000E-4	3.083E-4	3.333E-4	HRI<1
	Children	6.668E-4	5.833E-3	6.000E-3	6.168E-4	6.668E-4	HRI<1
Ni	Male	1.115E-2	1.100E-2	9.133E-3	5.285E-4	9.285E-3	HRI<1
	Female	1.300E-2	1.284E-2	5.333E-3	6.165E-4	1.084E-2	HRI<1
	Children	2.600E-2	2.566E-2	2.134E-2	1.234E-2	1.167E-2	HRI<1
Fe	Male	2.897E-1	1.024E-2	2.253E-2	4.734E-3	2.653E-4	HRI<1
	Female	4.581E-2	1.024E-2	2.629E-2	5.524E-3	2.381E-5	HRI<1
	Children	9.161E-2	2.390E-2	5.257E-2	1.105E-2	4.761E-5	HRI<1
Pb	Male	1.429E-2	1.214E-2	1.286E-1	1.142E-2	1.286E-2	HRI<1
	Female	1.667E-2	3.543E-3	1.500E-1	1.333E-2	1.500E-1	HRI<1
	Children	3.333E-2	2.833E-2	3.000E-2	2.668E-2	3.000E-2	HRI<1
Zn	Male	6.667E-4	4.570E-3	4.763E-4	1.048E-3	9.523E-6	HRI<1
	Female	7.777E-4	5.333E-3	5.557E-4	1.222E-3	1.111E-5	HRI<1
	Children	1.556E-3	1.067E-2	1.111E-3	2.444E-3	2.222E-5	HRI<1
Mn	Male	2.449E-3	8.571E-3	3.878E-3	7.757E-3	6,327E-3	HRI<1
	Female	2.857E-3	1.000E-2	4.524E-3	9.050E-3	7.379E-3	HRI<1
	Children	5.714E-3	2.000E-2	9.050E-3	2.552E-2	1.476E-2	HRI<1
As	Male	3.333E-1	3.430E-1	3.333E-1	3.333E-1	3.903E-1	HRI<1
	Female	3.890E-1	4.000E-1	3.890E-1	3.890E-1	4.557E-1	HRI<1
	Children	7.777E-1	8.000E-1	7.777E-1	7.777E-1	9.110E-1	HRI<1
Hg	Male	5.714E-3	6.286E-3	9.714E-3	7.428E-3	2.286E-3	HRI<1
	Female	6.666E-3	7.334E-3	1.133E-2	8.666E-3	2.666E-3	HRI<1
	Children	1.333E-2	1.467E-2	2.266E-2	1.733E-2	5.334E-3	HRI<1

Source: Author's Field Survey, 2020. GW1=Mile 4 Dumpsite (Apara well 10 Elijiji opposite C Bernett Special Hospital, Rumueme), GW2=Mbodo Aluu Dumpsite off OPM along Tam David-West Airport Road, GW3= Eneka Dumpsite-

Rukporkwu Eneka link Road Rumuopu, GW4=RIWAMA Dumpsite Mbodo Aluu before Checkpoint along Tam David-West Airport Road, GW5=Control close to Jephtha Comprehensive School along East-West Road.

More so, during the **wet season**, the health risk index **(HRI)** of adult male, female and children concentration values for Cd, Cu and Ni ranged from 5.714E-2 to 1.3720E-1 mg/kg/person/day, 6.666E-2 to 1.600E-1 mg/kg/person/day, 3.200E-2 to 3.066E-1 mg/kg/person/day; 2.858E-4 to 5.573E-3 mg/kg/person/day, 3.333E-4 to 6.500E-3 mg/kg/person/day, 6.665E-4 to 1.300E-2 mg/kg/person/day; 5.700E-3 to 1.857E-2 mg/kg/person/day, 6.665E-3 to 2.165E-2 mg/kg/person/day, 1.334E-2 to 4.33E-2 mg/kg/person/day, correspondingly. Fe, Pb and Zn with respect to adult male, female and children had concentration values which ranged from 3.306E-3 to 4.057E-2 mg/kg/person/day, 2.0857E-3 to 4.732E-2 mg/kg/person/day, 5.714E-3 to 9.462E-2 mg/kg/person/day; 7.143E-3 to 6.428E-2 mg/kg/person/day, 8.333E-3 to **4.000E+1** mg/kg/person/day, 1.668E-3 to 1.000E+1 mg/kg/person/day; and 1.619E-3 to 2.381E-3 mg/kg/person/day, 1.889E-3 to 2.778E-3 mg/kg/person/day, 3.377 to 5.557E-3 mg/kg/person/day, congruently (Table 4.).

Finally, the health risk index of Mn, As and Hg concentration values for adult male, female, and children ranged from 4.286E-3 to 1.200E-2 mg/kg/person/day, 1.119E-3 to 1.476E-2 mg/kg/person/day, 2.238E-3 to 2.952E-2 mg/kg/person/day; 3.713E-1 to 4.856E-1 mg/kg/person/day, 4.331E-1 to 5.767E-1 mg/kg/person/day, 8.667E-1 to **1.133E+1B** mg/kg/person/day, and 1.886E-2 to 3.314E-2 mg/kg/person/day, 2.200E-2 to 3.866E-2 mg/kg/person/day, 4.400E-2 to 7.734E-2 mg/kg/person/day, respectively (Table 4).

Table 4: Health Risk Index (HRI) by Ingestion (mg/kg/day) for adult Male, Female, and Children during the Wet Season.

Parameter	Gender	GW1	GW2	GW3	GW4	GW5	Remark
Cd	Male	5.714E-2	1.200E-1	1.314E-1	1.200E-1	1.372E-1	HRI<1
	Female	6.666E-2	1.400E-1	1.533E-1	1.400E-1	1.600E-1	HRI<1
	Children	1.334E-1	2.800E-1	3.066E-1	2.800E-1	3.200E-2	HRI<1
Cu	Male	8.573E-4	2.858E-4	1.286E-3	5.573E-3	4.285E-3	HRI<1
	Female	1.000E-1	3.333E-4	1.500E-3	6.000E-3	5.000E-3	HRI<1
	Children	2.000E-3	6.665E-4	3.000E-3	1.300E-2	1.000E-2	HRI<1
Ni	Male	1.857E-2	5.700E-3	5.715E-3	1.000E-2	0.857E-2	HRI<1
	Female	2.165E-2	6.665E-3	6.665E-3	1.167E-2	1.000E-2	HRI<1
	Children	4.334E-2	1.334E-2	1.334E-2	2.334E-2	2.000E-2	HRI<1
Fe	Male	4.057E-2	1.229E-2	2.449E-3	3.306E-3	3.387E-3	HRI<1
	Female	4.737E-2	1.433E-2	2.857E-3	3.857E-3	3.953E-3	HRI<1
	Children	9.467E-2	2.867E-2	5.714E-3	7.143E-3	7.904E-3	HRI<1
Pb	Male	4.285E-2	5.715E-2	6.428E-2	7.143E-3	3.428E-2	HRI<1
	Female	5.000E-2	6.668E-2	7.500E-2	8.333E-3	**4.000E+0**	HRI<1
	Children	1.000E-1	1.333E-1	1.500E-1	1.668E-3	8.000E-2	HRI<1
Zn	Male	1.619E-3	2.381E-3	1.714E-3	1.819E-3	1.619E-3	HRI<1
	Female	1.889E-3	2.778E-3	2.000E-3	2.122E-3	1.889E-3	HRI<1
	Children	3.779E-3	5.557E-3	4.000E-3	4.243E-3	3.777E-3	HRI<1
Mn	Male	8.364E-3	1.265E-2	4.286E-3	9.593E-3	9.593E-3	HRI<1
	Female	9.764E-3	1.476E-2	5.000E-3	1.119E-3	1.119E-2	HRI<1
	Children	0.195E-3	2.952E-2	1.000E-4	2.238E-3	2.238E-2	HRI<1
As	Male	4.477E-1	4.667E-1	4.856E-1	4.000E-1	3.713E-1	HRI<1
	Female	5.222E-1	5.333E-1	5.767E-1	4.667E-1	4.333E-1	HRI<1
	Children	**1.044E+0**	**1.089E+0**	**1.133E+0**	9.333E-1	8.667E-1	HRI<1
Hg	Male	2.972E-2	3.314E-2	2.800E-2	2.058E-2	1.886E-2	HRI<1
	Female	3.466E-2	3.866E-2	3.267E-2	2.400E-2	2.200E-2	HRI<1
	Children	6.934E-2	7.734E-2	6.552E-2	4.800E-2	4.400E-2	HRI<1

Source: Author's Field Survey, 2020. GW1=Mile 4 Dumpsite (Apara well 10 Elijiji opposite C Bernett Special Hospital, Rumueme), GW2=Mbodo Aluu Dumpsite off OPM along Tam David-West Airport Road, GW3= Eneka Dumpsite-Rukporkwu Eneka link Road Rumuopu, GW4=RIWAMA Dumpsite Mbodo Aluu before Checkpoint along Tam David-West Airport Road, GW5=Control close to Jephtha Comprehensive School along East-West Road.

However, during the wet season, there is a variation on the overall HRI. In sample location five (GW 5: Control station) for lead (**Pb**), the computed value for the adult female **4.000E+1** is very much higher (HRI>1) than the regulatory standard including its oral reference dose and thus exceeds the recommended standard (HRI<1) (Table 4). Also, in sample locations GW1, GW2, and GW3 (in the children concentration values) for Arsenic (**As**), the result (**1.044E+1, 1.089E+1, and 1.133E+1**) was slightly higher (HRI>1) than **unity** (HRI<1). This indicates concern for public health interest because the continuous ingestion of this lead (Pb) by adult females and Arsenic (As) by children could lead to bioaccumulation of such elements and thus could pose health challenges in the future for the recipients. Therefore, the non-carcinogenic adverse health effect cannot be overlooked. This is in line with a similar study carried out by [2] who reported HRI >1. All the other parameters were far less than the recommended standard and thus will pose no challenge to public health when being exposed to via ingestion.

Pollution Index (PI) of Each Heavy Metal

The pollution index of each metal during the dry and wet season was computed by the concentration of each metal value all over the US EPA Standard of that metal (Equation 3) (Table 5 and 6). Cd had a mean of 1.720E-1 and ranged from 4E-2 to 6E-1, Cu had a mean of 2.920E-1 and ranged from 2.7E-1 to 3.1E-1 while Ni had a mean of 3.760E-5 and ranged from 3.5E-5 (Table 3a. Fe, Pb and Zn mean 1.256 and ranged from 1.670E-3 to 3.21 (i.e., PI>1); 1.180E-1 and ranged from 1.100E-1 to 1.3E-1; 2.844E-3 ranged from 2.000E-5 to 1.00E-3 respectively (Table 3a). However, Mn, As and Hg had varied means (5.680E-1, 3.640E-1 and 5.500E-2) and ranged from 2.4E-1 to 8.4E-1, 4.1E-1 to 3.5E-1, and 2.000E-2 to 8.500E-2 respectively (Table 5).

During the **wet season**, Cd mean (**3.960E-1**) ranged from 2.000E-3 to 4.800E-1 while Cu mean (**1.816E+1**) ranged from 1.390E-1 to **6.000E+1**and Ni mean (6.800E-2) ranged from 1.300E-1 to 7.000E-2 (Table 7). Furthermore, the mean value for Fe (**1.013E+0**) ranged from 2.000E-1 to 3.310E+1, Pb mean (3.800E-1) ranged from 4.000E-1 to 6.000E-1 and Zn mean (**3.928E-2**) ranged from 3.400E-3 to 5.000E-3. Mn with mean (**8.720E-1**) ranged from 4.200E-1 to **1.240E+1** while As with mean (**4.52E-1**) ranged from 3.900E-1 to 5.100E-1 and Hg with mean (**2.290E-1**) ranged from1.650E-1 to 2.900E-1 respectively (Table 6).

Table 5: Pollution Index (PI) of each Metal across Groundwater sampling location during the Dry Season

Parameters	GW1	GW2	GW3	GW4	GW5	Average
Cd	6E-2	8E-2	4E-2	8E-2	6.000E-1	1.720E-1
Cu	3.1E-1	2.7E-1	2.8E-1	2.9E-1	3.100E-1	2.920E-1
Ni	4E-5	3.5E-5	3.6E-5	3.7E-5	4.000E-5	3.760E-5
Fe	**3.21E+0**	8.4E-1	**1.84E+0**	3.9E-1	1.670E-3	**1.256E+0**
Pb	1.3E-1	1.1E-1	1.2E-1	1.1E-1	1.200E-1	1.180E-1
Zn	1.4E-3	9.6E-3	1E-3	2.2E-3	2.000E-5	2.844E-3
Mn	2.4E-1	8.4E-1	3.8E-1	7.6E-1	6.200E-1	5.680E-1
As	3.5E-1	3.5E-1	3.5E-1	3.5E-1	4.1E-1	3.640E-1
Hg	5.000E-2	5.500E-2	8.5E-2	6.5E-2	2.000E-2	5.500E-2

The concentration variability of the pollution index of the heavy metals in this study indicated that Iron (Fe) with a mean value of **1.256E+0 is higher** than unity (PI>1). Also, at GW1 and GW3, Fe values appeared to be higher (PI>1) than unity: **3.21E+0** and **1.84E+0** respectively (Table 5). This shows a great public health concern mostly at GW1. However, all other parameters were far below the regulatory standard of being unity (i.e., PI<1) during the dry season. Furthermore, in the wet season, the mean value of Cu was **1.816E+1** which differs significantly from the dry season mean of **2.920E-1**. Similarly, Cu at GW4 had a concentration value of **6.000E+0** which is significantly very much higher than unity (P<1). The lowest or minimum value of Cu **1.3900E-1** was recorded in GW3 while its maximum value **9.200E-1** aside from the GW4 was recorded in GW1 (Table 5).

Table 6: Pollution Index (PI) of each Metal across Groundwater sampling location during the Wet Season

Parameters	GW1	GW2	GW3	GW4	GW5	Average
Cd	2.000E-3	4.200E-1	4.600E-1	4.200E-1	4.800E-1	3.960E-1
Cu	9.200E-1	3.100E-1	1.3900E-1	**6.000E+0**	4.600E-1	**1.816E+0**
Ni	1.300E-1	4.000E-2	4.000E-2	7.000E-2	6.000E-2	6.800E-2
Fe	**3.310E+0**	**1.003E+0**	2.000E-1	2.700E-1	2.8E-1	**1.013E+0**
Pb	4.000E-1	5.300E-1	6.000E-1	7.000E-2	3.200E-2	3.840E-1
Zn	3.400E-3	5.000E-3	3.600E-3	3.820E-3	3.400E-3	3.928E-2
Mn	8.200E-1	1.240E+0	4.200E-1	9.400E-1	9.400E-1	8.720E-1
As	4.700E-1	4,700E-1	5.100E-1	4.200E-1	3.900E-1	4.520E-1
Hg	2.600E-1	2.900E-1	2.500E-1	1.800E-1	1.650E-1	2.290E-1

The overall pollution index (**OPI**) status of the groundwater revealed that **Cd** had an OPI of **4.414E-1** during the **dry season** while its value during the **wet season** was **4.400E-1**. The OPI for **Cu** during the **dry season** was **3.008E-1** and its corresponding value during the **wet season** was **4.433E+0** whereas **Ni** had an OPI value of **3.882E-5** with a corresponding value of **1.037E-1** during the **wet season** (Table 7). **Fe, Pb,** and **Zn** had an OPI of **2.437E+0, 1.245E-1, and 7.080E-3** during the **dry season** while their corresponding values during **the wet season** were **2.448E+0, 4.251E+0,** and **4.494E-3**. Furthermore, the OPI values for manganese (Mn), arsenic (As), and mercury (Hg) during the dry season were **7.173E-1, 3.877E-1,** and **6.023E-1** while their corresponding values for the wet season were **1.072E+0, 4.819E-1,** and **2.613E-1** (Table 7). The overall pollution index indicates that Cu, Fe. Pb and Mn PI are higher than the regulatory standard (P<1). This calls for public health concerns.

Again, the pollution index (PI) of the heavy studied revealed that at GW1 and GW3, Fe is higher than regulatory standard during the dry season. In the wet season, at GW4, Cu is much higher than the regulatory standard while Fe is moderately high in GW2 and at GW1 it is excessively high. In living organisms, iron (Fe) is an essential metal for humans. Proteins and many enzymes, including hemoglobin, and myoglobin have iron as a major component. Iron deficiency could lead to anaemic and lethargy conditions mostly among children under five (5) years, immunocompromised individuals, and pregnant women, influencing them to frequent and several disease conditions [31, 2].

Table 7: Overall Pollution Index (PI) of Each Heavy Metal

Seasonal Variation	Cd	Cu	Ni	Fe	Pb	Zn	Mn	As	Hg
PI (DS)	4.414E-1	3.008E-1	3.882E-5	2.437E+0	1.245E-1	7.080E-3	7.173E-1	3.877E-1	6.023E-1
PI (WS)	4.400E-1	4.433E+0	1.037E-1	2.448E+0	4.251E+0	4.494E-3	1.072E+0	4.819E-1	2.613E-1
RfD	5E-4	3E-4	2E-2	7E-1	4E-3	3E-1	1.4E-1	3E-4	5E-4
US EPA	5E-3	1.3E-3	1E-1	3E-1	1.5E-2	5.0	5E-2	1E-2	2E-3

Source: Author's Field Survey, 2020. DS=Dry Season, WS=Wet Season, PI=Pollution Index, RfD=Reference dose by ingestion (mg/kg/day) for non-carcinogenic from US EPA, 2000d, 2005; FAO/WHO PTWI, 2004; US EPA IRIS, 2006.

More so, a neurological consequence could result from the high concentration of Fe [32]. Also, Mn is slightly high at GW2. At low toxicity, Mn has substantial biological importance. According to [33], having high values of Mn in drinking water is a common issue. Associated levels of Mn in drinking water could accentuate children's reasoning or intellectual behavioural problems [34]. High levels of manganese inhibit the absorption of dietary iron which could lead to iron-deficiency anaemia consequent upon long-term exposure to manganese in high concentrations. Manganese toxicity could lead to symptoms like those of Parkinson's disease e.g., tremors and stiff muscles, whereas the excessive intake of Mn could also lead to hypertension among patients older than 40 years [35].

CONCLUSION

From the determination of the heavy metal concentration of groundwater in the study area, we obtained better knowledge and understanding of the impact of waste dumpsites on the environment and the potential health risk associated to humans. Some of the heavy metal evaluated exceeds limit. The health risk index of these metals Pb in the control (GW5) for adult female and As in GW1, GW2 and GW3 for children during the wet season was so high. Values were higher than the regulatory standard. The health implication of this is not far-fetched. Again, the pollution index of Pb, Fe, Cu and Mn indicated a major health concern as their values exceed both the oral RfD and the regulatory standard (Unity HRI<1). The observed heavy metal contamination may have resulted from anthropogenic activities (unsanitary waste disposal at dumpsites).

Recommendations

1. Dumpsites should be located very far from residential areas.
2. Government should provide sanitary engineered Dumpsites.
3. Citizen should be educated on the environmental impacts of waste management and its public health implication.

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COMPETING INTEREST

Authors have declared that no competing interest exist.

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