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Leaching matrix of selected heavy metals from soil to ground water sources in active dumpsites: A case study of Southern Nigeria.

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Abstract:
Waste dumpsite poses immense risk to man and the environment. The study evaluated the concentration of five heavy metals in soil and borehole water at selected active dumpsites (Eleme, Eliozu, Eneka, Oyigbo and Yenagoa) in Southern Nigeria. 30g soil samples were collected at four quadrants at a depth of 0–15 cm for each dumpsites using soil auger and control samples were collected 25km away (Farm land). 20ml of borehole water samples were sampled from Eneka, Eleme, Woji and control site respectively. The soil and borehole water were well packaged, labelled and transported to the laboratory for standard analytical methods using Atomic Absorption Spectrophotometer. The mean pH value of soil samples ranged from 5.70 – 6.63 indicating slight acidity as compared to borehole water, which varied between 6.85 – 7.27 that were within WHO accepted limits. The mean heavy metals soil values were between As (nd – 0.45 mg/kg), Cr (nd – 2.21 mg/kg), Cu (6.05 – 51.87 mg/kg), Mn (3.24 – 37.91 mg/kg), Ni (nd – 13.50 mg/kg). Borehole water heavy metal samples ranged from Cr (0.01 - 0.20 mg/L), Cu (0.01 – 0.08 mg/L), Mn (nd – 0.02 mg/L), while As and Ni were not detected. Partial and full correlation matrices were conducted between soil and borehole water samples; they showed positive and negative correlation across pH and metals due to leaching infiltration and chemical interaction from soil to water source. Principal component analysis conducted had 72% cumulative variance with three factors influenced by heavy metal percolation from soil to water sources. Human health and exposure risk assessment showed that chronic daily intake (CDI) were dominant for inhalation and least for dermal for soil, while dermal contact was dominant, and ingestion was least for borehole water. Hazard index were > 1 for soil and < 1 for borehole water. Cumulative Cancer risk were within USEPA acceptable limits. The recipients (adults and children) reveals that children are more at risk compared to adults from soil exposure (inhalation) over a long period. Therefore, children should not have close interaction with waste dumpsites as collectors. Finally, waste dumpsites should have treatment and containment measures to prevent leaching and emission across environmental matrices and human contact.

Keywords: *Dumpsite soil; cancer risk; Heavy metals; correlation matrices; hazard index; borehole water; Nigeria.*

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I. Introduction

The recent urbanization, industrialization and population growth in Southern Nigeria has led to rapid increase in domestic, municipal and industrial wastes in the environment. [1] These waste could be degradable (organic) or non-degradable (solid waste) that causes tremendous issues to environmental matrices.

Solid waste consist of non-biodegradable materials such as clothes, glass, ceramics and metal cans, paper, plastics, rubber, leather, bottles, ashes, street sweepings, abandoned vehicles, non-hazardous industrial waste, construction and demolition waste. [2] These solid wastes are deposited at large dumpsites, burnt openly, which releases harmful chemical pollutants to the environment that adversely affects passers-by and those living within the vicinity of the dumpsites. [1]

Waste dumps are source of various environmental and health hazards. The decomposition of organic materials, which produces methane, which enhances greenhouse effect, may cause explosions and produce leachates that pollute surface and ground water. It distorts the aesthetic quality of the environment. [3] Furthermore, toxic and hazardous wastes when burnt with other solid waste like asbestos fibre have found to introduce potential carcinogenic fibre to the smoke plume. [3, 4]

In Southern Nigeria especially Port Harcourt and Yenagoa, solid wastes constituents are from petrochemical industries, [5] automobiles workshops, [6, 7] household preparation, cooking and serving of food, [8] market waste, storage and sales of produce and meals. [9] These wastes at dumpsites attract birds, rodents and insects as they feed at the dump, transmit diseases to human living within the vicinity, cause the release of unpleasant stenches, and threaten the aesthetics of the environment. [3, 10 -13] Due to the nature of the waste, these

lead to release of heavy metals into the soil that infiltrate into water matrices and jeopardize the environment and human health over long period. [14,15]

Heavy metals are found naturally in the earth, and become concentrated because of anthropogenic activities. Heavy metals are metals that possess a specific density of more than 5g/cm3 and adversely affect the environment and living organisms. [16] Heavy metal contamination have harmful effects on the receiving environment and human health due to their toxicity even at low concentration, persistence and bioaccumulation levels. [17, 18] Among all polluting component, heavy metals have received a paramount attention to environmental scientists due to their toxic nature, accumulation and persistent in soils at an environmentally hazardous level. [19]

Studies have shown that waste dumpsites may increase heavy metal concentration in soil and underground water. [20] These may have tremendous effects on soils, crops and human health. [21] Thus, the environmental impacts of waste dumpsites are greatly influenced by these heavy metal contents over a long period. Hence, environmental management of solid wastes, which contains high concentrations of these metals, is of interest to public health experts, environmental policy makers and regulatory agencies. People must be aware and educated to know the effects of indiscriminate disposal of waste.

Therefore, this study aims to assess the concentrations of selected heavy metals in soils and selected water boreholes around the selected waste dumpsites in South-South Nigeria and their carcinogenic human health risks.

II. Materials and Methods

2.1 Description of study area

In the study, we assessed six major solid waste dump sites that is five (5) located at Port Harcourt and one (1) at Yenagoa of South-South Nigeria were selected. The study area is characterized by tropical dry seasons (November to February) and wet season (March to October) with a mean annual rainfall increasing from 2000mm around the northern border to about 4500mm around the coastal margin [22]. The dumpsites is surrounded by local and international companies, automobile spare part markets, gasoline stations, automobile repair workshops, electrical / electronic market, and residential houses. In addition to the waste dump areas, adults including children are involved in day-to-day business of picking, sorting and packaging different reusable scraps for sells to intermediaries and merchants before getting to industries for reuse. Figure 1 shows the study area involved for the study.

Eleme
Latitude: 04°79'94"N
Longitude: 06°54'48.7″E

Eliozu
Longitude: 07°11'98"°E
Latitude: 04°54'16.4″

Eneka
Latitude: 04°53'34.1″N
Longitude: 06°54'48.7″E

Oyigbo
Latitude: 04°53'07.4″N
Longitude: 07°00'50.1″E

Woji
Latitude: 04°82'83"N
Longitude: 07°05'79"E

Yenagoa
Latitude: 04°58'59.20″N
Longitude: 06°19'18.2″E

Figure 1: Typical open waste dumpsites in Southern Nigeria.

2.2. Sample collection and preparation

Soil samples were collected with soil auger and a spatula at a depth of 0 – 15 cm after removing the overlying wastes. Soil samples were collected at the control sites located at a distance 200 meters from the dumpsite, which is a farmland with minimal human activity. Each dumpsite were sub divided into four quadrants, where soil samples were sampled at four spots of about 10 - 30 m (East, West, South and North) distance apart from each dumpsite were collected from each quadrant and homogenized into a composite sample. The composite soil samples were air-dried at room temperature for 48 hours. The samples were disaggregated using porcelain pestle and mortar, and sieved with a 2-mm nylon mesh to give the fine earth fraction. They were stored in labelled tight polythene bags and were taken to the laboratory for further analysis. Water samples were collected from four boreholes (four different points in each location and mixed to produce a composite sample) around the different studied dumpsite into 500 mL sterile bottles. The samples were transported to the laboratory and kept in a refrigerator and were analysed using procedure of standard methods.

2.3. Analysis of soil and water samples

2.3.1. Assessment of Soil and water pH

The pH of the soil sample were determined in a 1:1 soil to distilled water ratio. 10 g of soil sample weighed from each dumpsite were added to 10 ml of distilled water and stirred vigorously later allowed standing for 30 minutes. The pH meter electrode were rinsed with distilled water, inserted into the sample solution and a stable reading were taken while the pH values of the water samples were measured *in situ* using pH meter. [23] Triplicate pH values were taken to get an average pH value respectively.

2.3.2. Heavy metal assessment of soil and water samples

2.0 g of the dried-sieved soil samples were weighed with a digital weighing balance into 125 ml beaker. The soil samples were digested with 30 ml aqua-regia (65% Nitric acid: 35% hydrochloric acid) for 3 hours on a hot plate at 45℃. This were done to reduce the interference of organic matter. The digested samples were allowed to cool at room temperature and filter using Whatmann filter paper into 100ml volumetric flask. The sides of the beakers were washed with deionized water, diluted to a volume of 25 ml. The sample transferred into the appropriate test tube. [23] The digested soil was presented to the flame type atomic absorption spectrophotometer (FAAS) (Model VARIAN AA240FS) for Arsenic, Chromium, Copper, Manganese and Nickel determination. Triplicate determinations per sample were taken.

Heavy metal analysis in water sample were done according to APHA [23] standard methods. The water samples were filtered using a Whatmann No 42 filter paper, and 100 ml of the filtrate were then measured into a beaker. In addition, 15 ml concentrated nitric acid solution and 10 ml of 50% concentrated hydrochloric acid solution were added. The content were evaporated to almost dryness on a hot plate and 7 ml of 50% concentrated hydrochloric acid added and heated for 10 minutes. The solutions were allowed to cool, and then distilled water added to each and filtered into a 100 ml Pyrex volumetric flask using a Whatmann No 42 filter paper and made up to meniscus level with distilled water. The samples were analysed for heavy metals using Flame Atomic Absorption Spectrometer (Model. VARIAN AA240FS). Triplicate determinations per sample were taken. The limit of detection of the measured elements from the soil and water samples are: As = 0.001 mg L-1, Cr = 0.006 mg L-1, Cu = 0.003 mg L-1, Ni = 0.010 mg L-1, Mn = 0.002 mg L-1.

2.3.3 Statistical analysis

Data obtained from soil and water samples were subjected to analysis using the Statistical Package for Social Science (SPSS) 20.0 and Microsoft Excel 2016 software. Data were reported as mean ± standard deviation (SD) and were analyzed using one-way analysis of variance (ANOVA). Correlation analysis was done using Pearson Correlation test to assess elemental relationship in the studied areas.

2.4 Human Health Risk Assessment Model

Human health risk assessment were carried out to estimate the nature and probability of adverse health effects in humans as a result of exposure to heavy metals through soil and water around the vicinity of the study areas for both adults and children respectively. The Risk assessment conducted on heavy metals were used by determining the chronic daily intake (CDI); thereafter evaluate the carcinogenic and non-carcinogenic impacts to adults and children through exposure matrices (dermal, inhalation and ingestion) for soil and water as shown in Equation (1– 5). [24,25]

2.4.1. Chronic daily intake (CDI) (mg/kg/day) of heavy metals in Soil media

$$\text{CDI-ingestion} = \left(\frac{\text{CS} \times \text{IRs} \times \text{EF} \times \text{ED} \times \text{RBA} \times \text{TR}}{\text{THQ}^{**} \times \text{BW} \times \text{AT}}\right) \quad (1)$$

$$\text{CDI-dermal} = \left(\frac{\text{CS} \times \text{SA} \times \text{K}_p \times \text{EF} \times \text{ED} \times \text{TR}}{\text{BW} \times \text{AT} \times \text{THQ}^{**} \times \text{GIABS}}\right) \quad (2)$$

$$\text{CDI-inhalation} = \left(\frac{\text{CS} \times \frac{1}{\text{VF}} \times \frac{1}{\text{PEF}} \times \text{EF} \times \text{ET}_{\text{ih}} \times 1\text{day}/24\text{hr} \times \text{ED}}{\text{AT}}\right) \quad (3)$$

Where CS = heavy metal concentration in dumpsite soil (mg/kg), IRs = soil ingestion rate (100mg/day–adults and 200mg/day–children) [24], EF = exposure frequency (350-day year-1) [24]. ED = exposure duration (26 years–adults and 6 years–children) [26] TR = target risk 1×10^6 kg/mg [25], RBA = relative bioavailability factor (0.6 for arsenic and 1 for other metals) [28], THQ** = target hazard quotient 0.1 for non-carcinogen only. [25], BW = body weight (80kg for adults and 15kg for children) [26], AT = averaging time (non-carcinogens = ED ×365days; carcinogen =70×365days) [27], SA = skin surface area (6032cm^2/day – adults and 2373 cm^2/day – children) [26]. AF = water adherence factor: (0.07mg/cm^2 – adults and 0.2mg/cm^2 – children) [28], Kp = dermal permeability constant (0.001cm/hr for both adults and children) [29], GIABS = fraction of contaminant absorbed in gastrointestinal tracts (unit-less) (1.0 for adults and children) [29], ETih = Exposure time (6hrs/days–adults and 9hrs/day–children). VF = Volatilization factor (adults and children: 1×10-5 m^3/kg for non-carcinogen; 0.006 for carcinogen calculation) [28], PEF = Particulate emission factor (1.36×109 m^3/kg for adults and children) [28].

2.4.2. Chronic daily intake (CDI) (mg/kg/day) of heavy metals in borehole water

$$\text{CDI-ingestion} = \left(\frac{\text{CS} \times \text{IR}_W \times \text{EF} \times \text{ED} \times \text{TF}}{\text{BW} \times \text{AT} \times \text{THQ}^{*}}\right) \quad (4)$$

$$\text{CDI-dermal} = \left(\frac{\text{CS} \times \text{SA} \times \text{K}_\text{p} \times \text{ET}_W \times \text{EF} \times \text{ED} \times \text{TF}}{\text{BW} \times \text{AT} \times \text{GIABS} \times \text{THQ}^{*}}\right) \quad (5)$$

Where: CS = heavy metal concentration in water (mg/L), IRw = daily water ingestion rate (L/day) (2.5L/day–adults and 0.78L/day–children) [26], EF = exposure frequency (350-day year-1) [24], ED = exposure duration (26 years–adults and 6 years–children), [26], TR = target risk (1×10^6 kg/mg) [25], THQ** = target hazard quotient 0.1 for non-carcinogen calculation only [25], BW = body weight (80kg for adults and 15kg for children) [26], AT = averaging time (non-carcinogens = ED ×365days; carcinogen =70×365days) [27], SA = skin surface area (19652cm2–adults and 6365cm2–children) [30], Kp = dermal permeability constant (0.001cm/hr for both adults and children) [29]. GIABS = fraction of contaminant absorbed in gastrointestinal tracts (unit-less) (1.0 for adults and children) [29], ETw = exposure time during work event (2h/event for adults and 4hr/event for children) [26].

The reference table for heavy metals carcinogenic and non-carcinogenic risk assessment are presented in (**Table 1)**.

2.4.3. Carcinogenic risk assessment

Carcinogenic risk assessment were determined using CDI of dermal, ingestion and inhalation as shown in equation (7) [31, 32].

$$\text{Risk}_{\text{total}} = \text{Risk}_{\text{der}} + \text{Risk}_{\text{ing}} + \text{Risk}_{\text{inh}}$$
$$= ([\text{CDI(der)} \times \text{CSF}] + [\text{CDI(Ing)} \times \text{OSF}] + [\text{CDI(Inh)} \times \text{IUR}]) \quad (7)$$

Where: Risk = a unit-less probability of an individual developing cancer over a lifetime, ADI (E) = average daily intake (exposure), CSF is Cancer slope factor of heavy metals (mg/kg/day), Risk $_{total}$ is the total excess lifetime cancer calculated from risk pathway.

2.4.4. Non-carcinogenic risk assessment

Non-carcinogenic risk assessment were performed using CDI of dermal, ingestion and inhalation as shown in equation (8) [31, 32].

$$HI = HQ_{der} + HQ_{ing} + HQ_{inh} = \left(\left[\frac{CDI(Der)}{RfD}\right] + \left[\frac{CDI(ing)}{RfD}\right] + \left[\frac{CDI(inh)}{RfC}\right]\right) \quad (8)$$

Where: HI = sum total of more than one hazard quotient of multiple exposure pathway, HQ = hazard quotient is a unit-less number for expressing the probability of an adverse health effect, CDI (E) = average daily intake (exposure), RfD = reference dose of heavy metals (mg/kg/day).

Table 1: Reference value for Heavy metals

Heavy metals	Dermal		Ingestion		Inhalation		
	CSF	RfD	OSF	RfD	IUR	RfC	Source
Arsenic	1.5	0.0003	1.5	0.0003	1.5	0.0003	[24]
Chromium (III)	NA	0.005	NA	1.5	NA	0.005	[25]
Chromium (VI)	NA	0.0003	0.5	0.003	41	0.0001	[25]
Copper	NA	0.024	NA	0.04	NA	NA	[33]
Manganese	NA	0.00005	NA	0.14	NA	0.00005	[25]
Nickel	NA	0.0056	NA	0.02	NA	0.0002	[25]

Where: CSF: cancer slope factor (mg/kg/day), OSF: oral slope factor (mg/kg/day), IUR: inhalation unit risk (mg/m^3), RfD: reference dose, RfC: reference concentration

III. Results and Discussion

3.1. Heavy metals composition in dumpsites in soil samples

(Table 2) reveals the mean concentration of pH and heavy metal analyzed from different waste dumpsites and control sites. Figure 2 shows the Pareto chart plots of different analyzed parameters in descending order of frequency, with cumulative line plot on secondary axis as percentage of total values.

The results obtained showed that pH values analyzed were relatively acidic for different waste dumps. Yenagoa was highest, while Woji was least, which indicates that pH is a useful tool for soil suitability. As assessed, the waste dumpsites contributed immensely to mobility factor from metallic ions and decaying organic matter that produces hydrogen ion (H^+) thus influencing the pH of environmental matrices. Lower pH values also influences high reactivity, dissolution and subsequently leach out heavy metals into water source over a long radius influencing taste, colour and aesthetic water quality [34]. The pH values obtained in this study are similar to that reported for dumpsites by other researches [35, 36]

Arsenic were found in small concentrations in all the soil dumpsites as Woji dumpsite and Eleme dumpsite had mean concentration of 0.45mg/kg and 0.33mg/kg, which indicates waste dump had close proximity to industrial waste compared to other locations, low use of materials containing arsenic and smelting activities at the studied dumpsites.

Chromium were detected in all the sampling sites except in Yenagoa dumpsite. The mean concentration of chromium in the dumpsite soils range from 0.48mg/kg (Oyigbo dumpsite) to 2.21mg/kg (Eneka dumpsite). Chromium concentrations in the dumpsite soils were generally above standard limits (0.05 mg/kg) set by WHO [37] as the values were within range of 1.00 – 4.50 mg/kg as reported by Ukpong *et al.,* [38]. Sources of chromium in the soil could be due to waste consisting of lead-chromium batteries, coloured polythene bags, empty diesel engines utilizing anti-corrosive agents and discarded plastic materials [39].

Copper were detected in all the sampling sites. The mean concentration of copper recorded from the various dumpsite soils range from 6.05mg/kg (control site 1) to 51.87mg/kg (Oyigbo dumpsite). This is in agreement with the results of Amusan *et al.,* [19] and it could be attributed to the availability of metal containing wastes at dumpsites, which eventually leaches into the underlying soils by rain deposition and runoffs. The mean concentration observed were above WHO [37] permissible limit of 3.5mg/kg for agricultural soils.

The mean concentration of manganese (Mn) in the soil samples ranged from 7.25mg/kg (Eneka dumpsite) to 37.91mg/kg (Oyigbo dumpsite). The concentration were lower compared to assessment done by Onyedika [40] for urban soils of Bauchi State and Musa *et al.,* [41] in North –Central dumpsites in Nigeria. These can be associated to soil pH, which is slightly acidic and makes the distribution of Mn slower.

Nickel concentration in the soil were found to be lower with range from ND to 10.9mg/kg (Woji dumpsite). The value of Ni in the soil were lower compared to Adefemi and Awokunmi, [42] and Awokunmi *et al.,* [43] assessments. Sources of nickel to the environment can be natural and anthropogenic, which include emissions from fossil fuel consumption, industrial production, use, and disposal of nickel compounds and alloys [44].

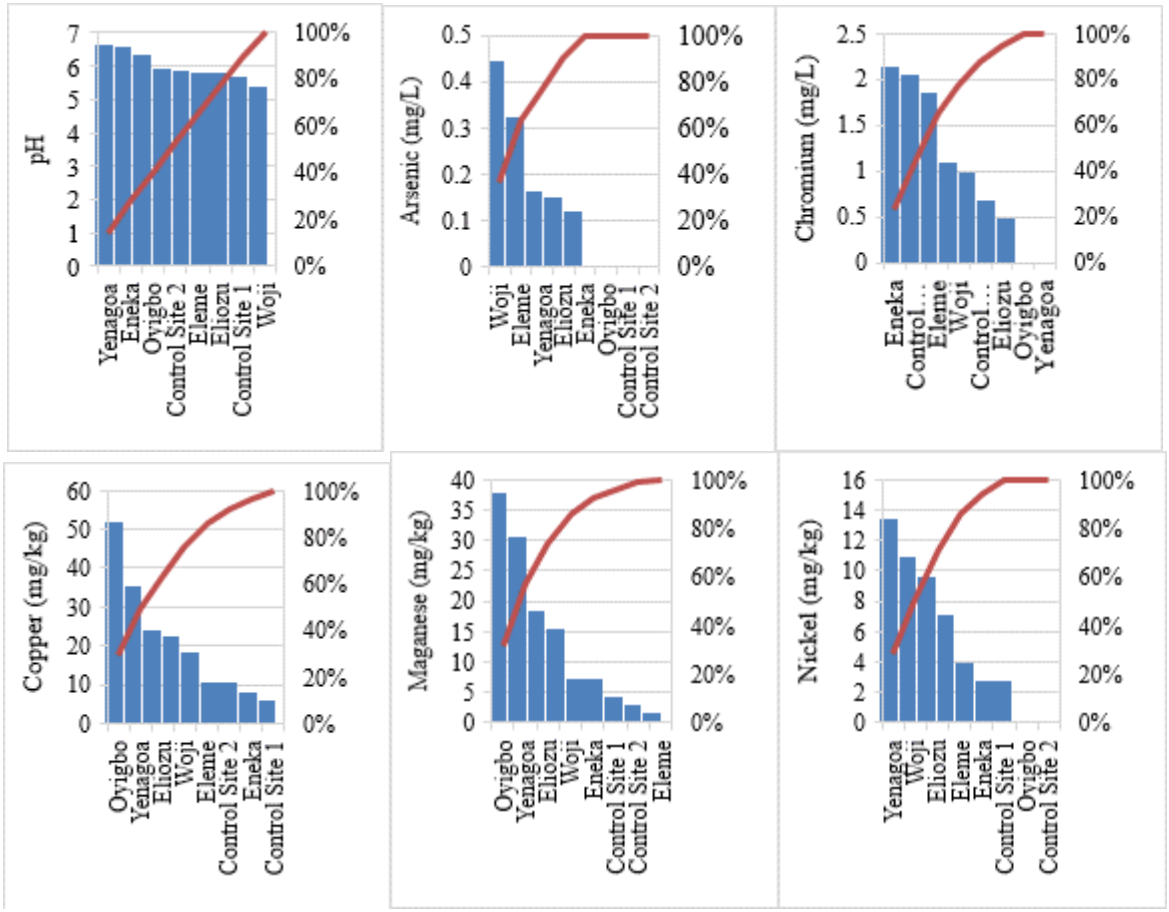

Figure 2: Pareto chart plot of Mean Concentration of pH and heavy metals in soil

Table 2. pH and heavy metal concentrations (mg/kg) in dumpsite soils of the study area

Dumpsite	pH	As	Cr	Cu	Mn	Ni
Eleme	5.91±0.015	0.33±0.002	1.87±0.017	18.57±0.076	1.65±0.015	7.20±5.77
Eliozu	5.85±0.012	0.14±0.012	0.69±0.03	24.28±0.058	18.68±0.015	9.60±0.03
Eneka	6.63±0.02	0.12±0.004	2.21±0.064	8.42±0.029	7.25±0.092	4.10±0.05
Oyigbo	6.39±0.015	ND	0.48±0.015	51.87±0.153	37.91±0.045	ND
Woji	5.7±0.58	0.45±0.003	1.08±0.019	22.98±0.176	15.69±0.081	10.90±0.02
Yenagoa	6.62±0.015	0.17±0.004	ND	35.63±0.126	30.64±0.031	13.50±0.02
Control Site 1	5.69±0.02	ND	2.07±0.018	6.05±0.05	4.32±0.042	2.80±0.03
Control Site 2	5.96±0.021	ND	0.97±0.016	10.68±0.12	3.24±0.006	ND
WHO Permissible Limit [37]	6.5-8.5	0.02	0.05	3.5	2.0	0.07

Results presented as mean ± standard deviation. No significant different at $p<0.05$.

3.2. Heavy metals composition in borehole water samples

(Table 3) reveals the mean concentration of pH and heavy metal analyzed from different borehole and control site. (Figure 3) shows the Pareto chart plots of different analyzed parameters in descending order of frequency, with cumulative line plot on secondary axis as percentage of total values.

Water is known to man to sustain life on the earth, it is one of the basic needs for human well-being [45, 46]. Pollution of surface and ground water by heavy metals and other organic contaminants has become a global issue because of their toxic, bioaccumulation and persistent nature in the environment [19]. The pH was relatively neutral, thus the borehole are okay for human consumption. Arsenic and nickel were not detected in all four-borehole water sampled. When there are presences of these metals, even at low concentration levels

they can cause health challenges to man and its environment [47, 48]. Absence of nickel and arsenic across the borehole water locations could be due to low proliferation of wastes containing arsenic and nickel.

The result of the analysis on borehole water shows that the highest metal concentrations were Cr (0.2mg/L) in Woji while the least heavy metal concentration was Mn (0.005) in Eleme. The high value of Cr at the different location of the water sample shows that chromium-containing wastes were dumped at the various studied areas, which infiltrate into the surface and underground water. The values of chromium observed in the borehole water were similar to Boateng *et al.,* [15] on ground water quality contamination and Elinge *et al.,* [49] on metals concentration in borehole waters in Aliero community. All the heavy metals detected in water samples where below WHO [47] permissible limit except chromium which is above 0.05 mg/l WHO permissible limit for drinking water. The low levels of the heavy metal concentration shows little amounts of pollutants across the study areas. This may be due to geologic influence and their lipophilic nature [48].

The values of Manganese, Mn recorded across the sampling sites were within 0.4 mg/l WHO [47] permissible limit, the control sample were not detected. Mn is released by acidic leaching from waste dumps to soil and ends in varying water sources [50,51]. The mean concentration of copper across the different borehole water locations were all below 0.05 mg/l WHO [47] permissible limit.

The values of copper in the present work were lower than the results of Nwoke and Edori [46] on concentration of heavy metals in borehole water from Ikono urban. Manganese and copper are known as essential nutrient responsible for body growth and functioning [52]. Irritation of the intestine stomach, problem of liver and kidney can result because over exposure of copper and Manganese or high concentration intake [45].

Table 3. Heavy metal concentrations (mg/L) in borehole water samples.

SAMPLE CODE	pH	As	Cr	Cu	Mn	Ni
Eneka	6.93±0.012	ND	0.016±0.001	0.002±0.002	0.012±0.002	ND
Eleme	6.85±0.021	ND	0.012±0.003	0.003±0.001	0.005±0.002	ND
Woji	7.09±0.006	ND	0.2±0.01	0.005±0.001	0.016±0.002	ND
Control Site 1	7.27±0.006	ND	0.021±0.003	0.001±0.001	ND	ND
WHO Permissible Limit [47]	6.5-8.5	0.01	0.05	0.05-1.5	-	0.02

Data presented as mean ± standard deviation. No significant different at $p<0.05$.

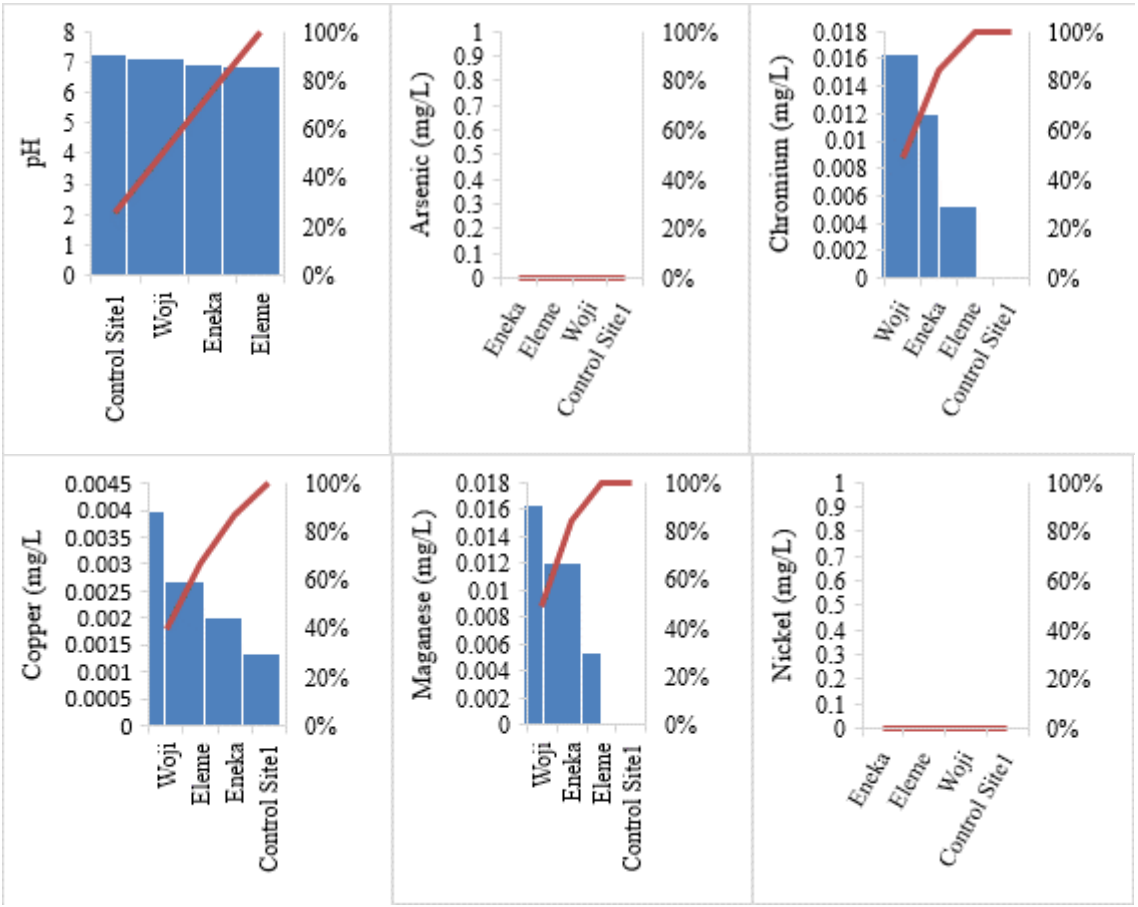

Figure 3: Pareto chart plot of Mean Concentration of pH and heavy metals in water

3.3. Correlation matrix and factor analysis of heavy metals

The relationships between dumpsite soil and borehole water samples were conducted for all the locations using correlation matrices and factor analysis to give comparative relationship. (Table 4) shows the partial correlation and correlation matrices of soil and borehole water samples. As seen for partial correlation, there were significant positive and negative relationship between variables in soil and borehole water respectively. Vertically, pH had positive correlation between Cr-soil, Cu-soil, and Mn-BH (0.51, 0.61, 0.71), while negative correlation were realized with As-soil and Mn-soil (-0.73, -0.62). As-Soil had positive correlation with Cr-soil, Cu-soil and Mn-BH and Cu-BH (0.76, 0.93, 0.94, 0.55), as Mn-soil had negative correlation (-0.95). Horizontally, Mn-BH correlated positively with Mn-soil, pH-soil, As-soil (0.94, 0.71, 0.94), while negative for Cr-soil, Cu-soil (-0.74, -0.93). Correlation matrices conducted had strong positive interaction compared to negative, as horizontal As-soil had positive correlation for Ni-soil, Mn-BH and Cu-BH (0.66, 0.61, 0.53). Vertical Cu-BH had positive correlation for As-soil, Ni-soil and Mn-BH (0.53, 0.59, 0.51) respectively. From the both correlation conducted, positive correlation indicates that as one variable increases, the other decreases, thus, we can state that there is strong relationship of similar waste component released into the soil leading to leachate infiltration into ground water. Negative correlation shows that there were different chemical interaction taking place in both the borehole and soil constituents correspondingly. Factor matrix (Principal component analysis) were conducted for soil and borehole water samples across the different locations as shown in (Table 5). Principal component analysis (PCA) is based on a multidimensional data to correlate variables to extract relevant knowledge using Microsoft Excel, 2016 – X real-Stats adds-in. according to Liu et al., [53]). Factor matrix are graded as strong (>0.75), moderate (0.75 to 0.50) and weak (0.50 to 0.30). Factor matrix conducted showed that there were three factors having 72.09% cumulative variances. Factor matrix (un-rotated) conducted as seen showed that Factor 1 had significant variance at 30.04% with Cu-soil and Mn-soil having strong relationship with Mn-BH and Cu-BH as the matrix reduced from soil to borehole water samples due to anthropogenic sources that impacts on leaching from the soil to water [54]. As seen from both factor analysis (unrotated and rotated varimax), we can postulate that some variable increased and vice-versa, which implies that they are from different sources (organic and inorganic chemicals) with varying chemical interactions and processes that influenced the chemical discharge from soil to water. In general, the concentrations of heavy metals in the soil dumpsites were higher than that of the borehole water samples, which implies that these metal

leaches into various environmental matrices. The variation of concentration of the heavy metals depends on the study area location of the borehole water and could be due to quantity and kind of waste been received across the study areas periodically.

Table 4: Partial and Full correlation matrices of soil and borehole water samples

	pH-soil	As-soil	Cr-soil	Cu – soil	Ni-soil	Mn-soil	pH-BH	Cr-BH	Mn-BH	Cu-BH
pH-soil	1	-0.733*	0.512*	0.613*	0.057	-0.621*	0.073	0.33	0.71*	0.415
As-soil	-0.236	1	0.755*	0.929*	0.286	-0.947*	0.305	0.401	0.942*	0.549*
Cr-soil	-0.236	0.052	1	-0.832*	-0.397	0.734*	-0.491	-0.319	-0.744*	-0.299
Cu -soil	0.351	-0.007	-0.767**	1	-0.283	0.981*	-0.419	-0.437	-0.925*	-0.396
Ni-soil	0.01	0.663**	-0.32	0.133	1	0.225	-0.328	0.115	-0.119	0.043
Mn-soil	0.44	-0.115	-0.80**	0.936**	0.197	1	0.35	0.439	0.938*	0.461
pH-BH	-0.33	-0.27	0.032	-0.49	-0.119	-0.348	1	0.521*	-0.44	-0.279
Cr-BH	-0.131	0.135	-0.21	-0.25	0.397	-0.05	0.74**	1	-0.301	0.106
Mn-BH	0.317	0.612**	-0.36	0.303	0.742**	0.425	-0.333	0.228	1	-0.512*
Cu-BH	0.104	0.53**	-0.40	0.395	0.593**	0.405	-0.139	0.338	0.512**	1

* Partial correlation matrices at 0.05
** Full Correlation matrices at 0.05

Table 5: Principal component analysis of soil and borehole water samples

	Factor Matrix (un-rotated)			Factor Matrix (rotated varimax)		
	1	2	3	1	2	3
pH-soil	0.407	-0.441	-0.026	0.529	-0.031	0.281
As-soil	0.408	**0.659**	**0.537**	-0.277	**0.892**	0.127
Cr-soil	**-0.737**	0.186	**0.519**	**-0.874**	-0.19	0.219
Cu –soil	**0.785**	**-0.518**	-0.116	**0.887**	0.139	0.303
Ni-soil	**0.645**	**0.627**	0.123	0.105	**0.887**	-0.161
Mn-soil	**0.814**	-0.445	-0.289	**0.952**	0.147	0.125
pH-BH	-0.451	0.443	**-0.749**	-0.204	-0.26	**-0.922**
Cr-BH	0.09	**0.704**	-0.651	0.018	0.305	**-0.914**
Mn-BH	**0.776**	0.353	0.214	0.295	**0.823**	0.085
Cu-BH	**0.714**	0.385	-0.033	0.348	**0.720**	-0.143
Eigenvalue	3.893	2.486	1.703	3.075	3.018	1.989
Variance (%)	30.036	23.393	18.662	30.646	20.457	20.988
Cumulative (%)	30.036	53.429	72.091	30.646	51.103	72.091

IV. Risk assessment

4.1. Risk assessment of soil samples

The carcinogenic and non-carcinogenic risk assessment were conducted using three exposure pathways (ingestion, dermal and inhalation) for soil samples.

4.1.1. Carcinogenic Risk assessment for adults and children

The chronic daily intake (CDI) for carcinogenic risk assessment were conducted for adults and children as represented in (Figure 4 and 5) respectively. The CDI – carcinogenic values for adults and children ranged in As (nd – 2.00e-07; nd – 4.93E-07), Cr (nd – 9.84E-07; nd – 2.42E-06); Cu (1.42E-08 – 2.31E-05; 1.05E-07 – 5.68E-05), Mn (3.88E-09 – 1.69E-05; 2.86E-08 – 4.15E-05), Ni (nd – 6.01E-06; nd – 1.48E-05). We can see that CDI values ranged from ND to 2.31E-05 for adults and ND to 5.68E-05 for children. In addition, ingestion pathway was highest, while dermal contact was least. In terms of decreasing cumulative CDI for locations, Oyigbo > Yenagoa > Eliozu > Woji > Eleme > Eneka > Control Site 1 > Control Site 2.

(Table 6) displays the cancer risk across different pathways for adults and children. The cancer risk were calculated from chronic daily intake of carcinogenic derivation. Having accessed the values displayed, one can comfortably state both adults and children are within USEPA permissible range values for carcinogenicity (1E-06 – 1E-04).

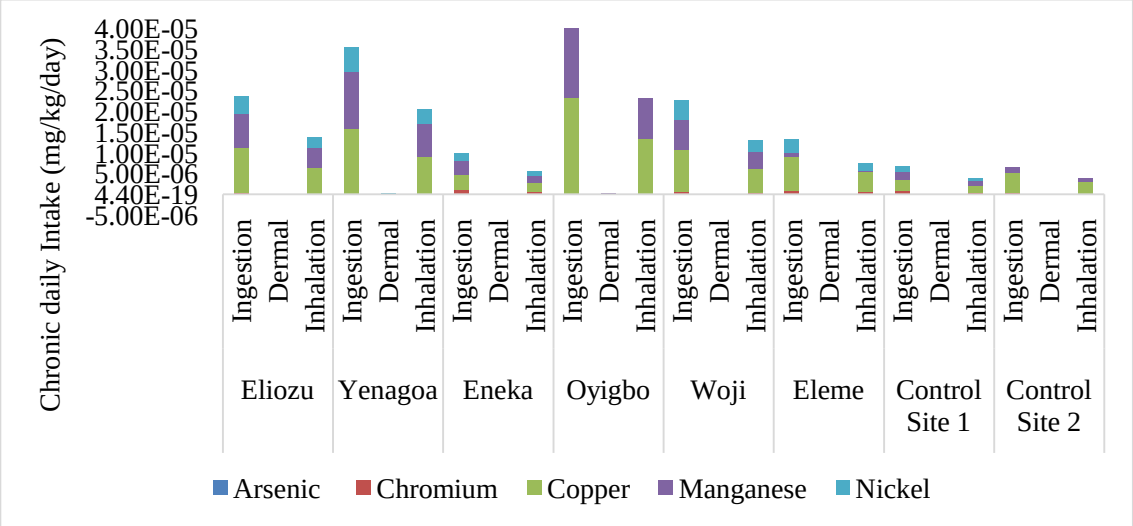

Figure 4: Chronic Daily Intake for carcinogens in heavy metals for adults

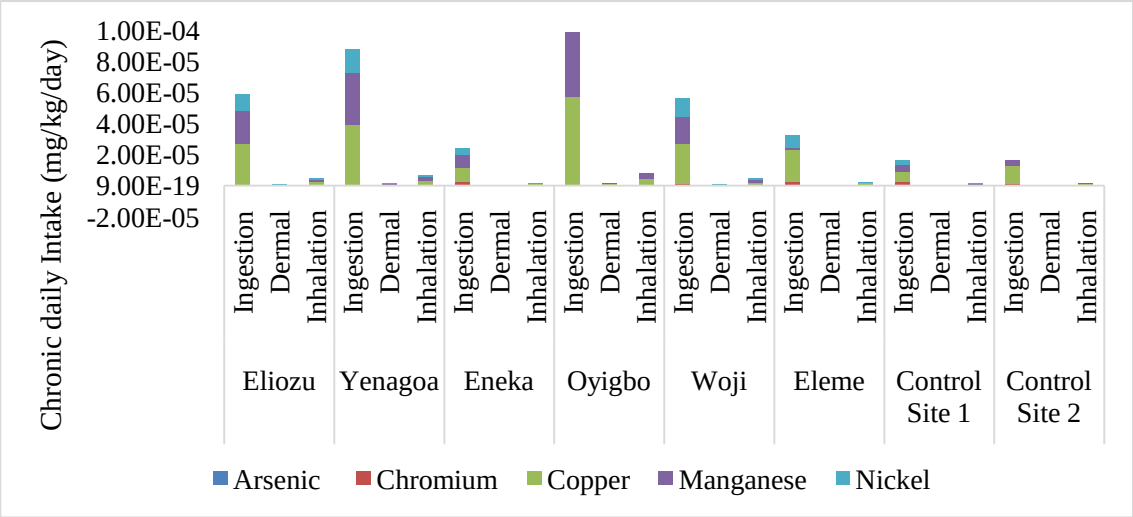

Figure 5: Chronic Daily Intake for carcinogens in heavy metals for children

Table 6: Cancer Risk of heavy metals across different pathways for adults and children

Location	Exposure pathway	Recipient	As	Cr-III	Cr-VI	Ni	Σ-Heavy metals
Eliozu	Ingestion	Adults	9.35E-08	1.54E-07	1.54E-07	ND	4.01E-07
		Children	2.30E-07	3.78E-07	3.78E-07	ND	9.86E-09
	Dermal	Adults	4.93E-10	ND	ND	ND	4.93E-10
		Children	3.64E-09	ND	ND	ND	3.64E-09
	Inhalation	Adults	5.38E-08	2.65E-08	7.25E-06	ND	7.33E-06
		Children	1.86E-08	9.18E-09	2.51E-06	ND	2.54E-06
Yenagoa	Ingestion	Adults	1.14E-07	ND	ND	ND	1.14E-07
		Children	2.79E-07	ND	ND	ND	2.79E-07
	Dermal	Adults	5.99E-10	ND	ND	ND	5.99E-10
		Children	4.42E-09	ND	ND	ND	4.42E-09
	Inhalation	Adults	6.53E-08	ND	ND	8.99E-10	6.62E-08
		Children	2.26E-08	ND	ND	3.11E-10	2.29E-09
Eneka	Ingestion	Adults	8.01E-08	ND	4.92E-08	ND	1.29E-07
		Children	1.97E-07	ND	1.21E-07	ND	3.18E-07
	Dermal	Adults	4.23E-10	ND	ND	ND	4.23E-10
		Children	3.12E-09	ND	ND	ND	3.12E-09
	Inhalation	Adults	4.61E-08	8.49E-08	2.32E-05	2.73E-10	2.33E-05
		Children	1.60E-08	2.94E-08	8.04E-06	9.46E-11	8.08E-06
Oyigbo	Ingestion	Adults	ND	ND	1.07E-08	ND	1.07E-08
		Children	ND	ND	2.63E-08	ND	2.63E-08
	Dermal	Adults	ND	ND	ND	ND	0
		Children	ND	ND	ND	ND	0

	Inhalation	Adults	ND	1.84E-08	5.04E-06	ND	5.06E-06
		Children	ND	6.39E-09	1.75E-06	ND	1.75E-06
Woji	Ingestion	Adults	3.01E-07	2.40E-07	2.40E-07	ND	7.81E-07
		Children	7.40E-07	5.92E-07	5.92E-07	ND	1.92E-06
	Dermal	Adults	1.59E-09	ND	ND	ND	1.59E-09
		Children	1.17E-08	ND	ND	ND	1.17E-08
	Inhalation	Adults	1.73E-07	4.15E-08	1.13E-05	7.26E-10	1.16E-05
		Children	5.99E-08	1.44E-08	3.93E-06	2.51E-10	4.00E-06
Eleme	Ingestion	Adults	2.20E-07	ND	4.16E-07	ND	6.37E-07
		Children	5.42E-07	ND	1.02E-06	ND	1.57E-06
	Dermal	Adults	1.16E-09	ND	ND	ND	1.16E-09
		Children	8.58E-09	ND	ND	ND	8.58E-09
	Inhalation	Adults	1.27E-07	7.19E-08	2.44E-05	4.80E-10	2.46E-05
		Children	4.39E-08	2.49E-08	8.46E-05	1.66E-10	8.47E-05
Control Site 1	Ingestion	Adults	ND	ND	4.61E-08	ND	4.61E-08
		Children	ND	ND	1.13E-07	ND	1.13E-07
	Dermal	Adults	ND	ND	ND	ND	0
		Children	ND	ND	ND	ND	0
	Inhalation	Adults	ND	7.96E-08	2.17E-05	1.87E-10	2.18E-05
		Children	ND	2.75E-08	7.53E-06	6.46E-11	7.56E-06
Control Site 2	Ingestion	Adults	ND	ND	2.16E-08	ND	2.16E-08
		Children	ND	ND	5.32E-08	ND	5.32E-08
	Dermal	Adults	ND	ND	ND	ND	0
		Children	ND	ND	ND	ND	0
	Inhalation	Adults	ND	3.73E-08	1.02E-05	ND	1.02E-05
		Children	ND	1.29E-08	3.53E-06	ND	3.54E-06

4.1.2. Non-Carcinogenic Risk assessment for adults and children

The chronic daily intake conducted for non-carcinogenic risk assessment are presented in (Figure 6 and 7) across three exposure pathways respectively. The CDI-non carcinogenic values for adults and children ranged from As: (nd – 3.87E-05; nd – 7.93E-05), Cr: (nd – 1.90E-04; nd – 3.90E-04); Cu: (3.98E-08 – 4.46E-03; 2.75E-06 – 9.14E-03); Mn: (1.09E-08 – 3.26E-03; 7.51E-07 – 6.68E-03); Ni: (nd – 1.16E-03; nd – 2.38E-03). (Table 7) shows the hazard quotient conducted across different exposure pathways for adults and children. Cumulative hazard quotient for ingestion and dermal contact were below 1 indicating no health effect, while inhalation were above 1; which means that there is tremendous health effect from prolong inhalation of these heavy metals.

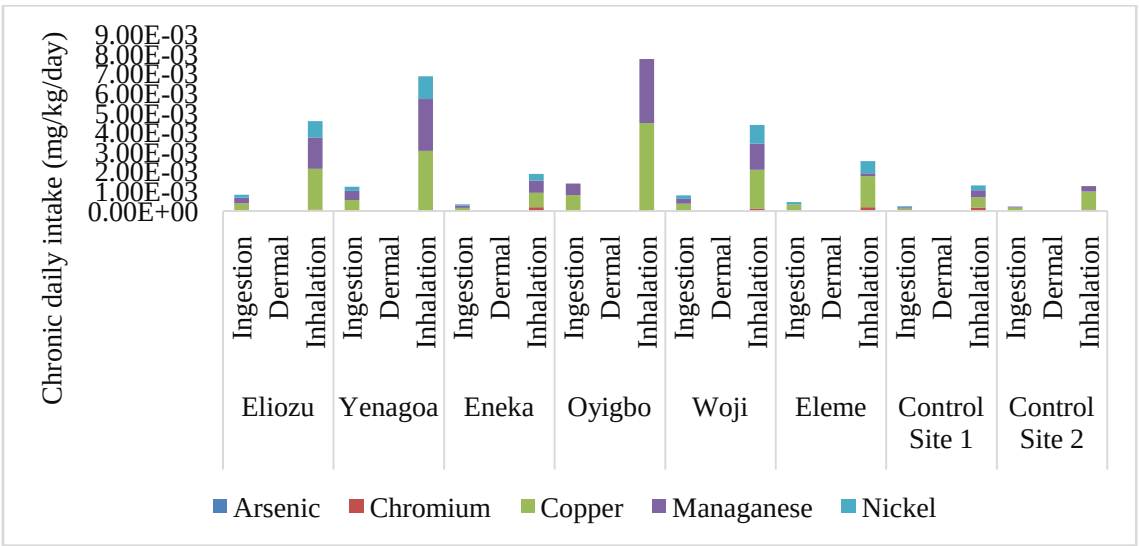

Figure 6: Chronic Daily Intake for non-carcinogens in heavy metals for adults

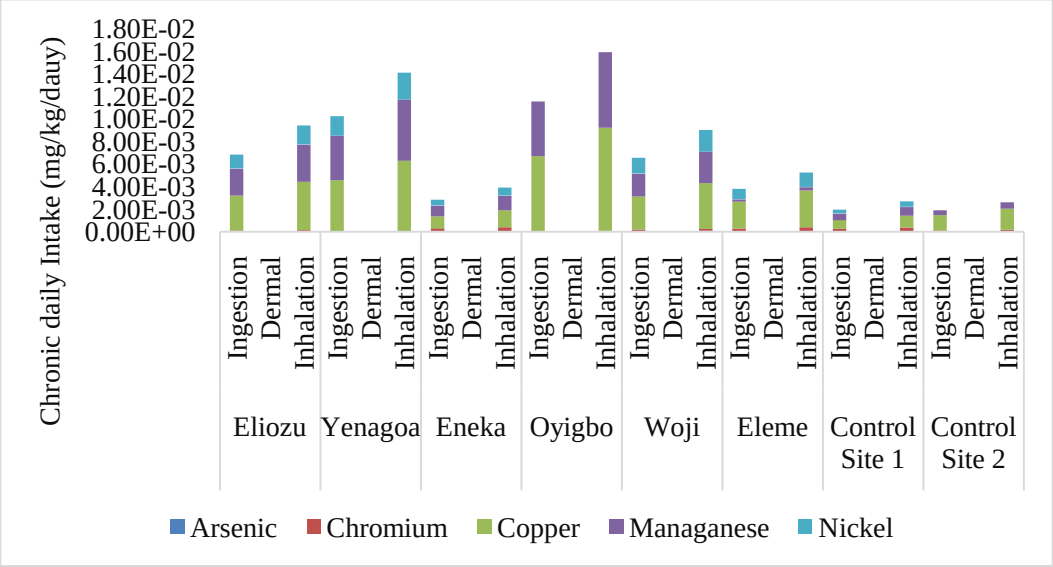

Figure 7: Chronic Daily Intake for non-carcinogens in heavy metals for adults

Table 7: Hazard quotient of heavy metals across different pathways for adults and children

Location	Exposure pathway	Recipient	As	Cr-III	Cr-VI	Cu	Mn	Ni	Σ-Heavy metals
Eliozu	Ingestion	Adults	7.27E-03	7.17E-06	3.58E-03	9.46E-02	2.08E-03	7.48E-03	2.99E-02
		Children	5.97E-02	5.88E-05	2.94E-02	7.76E-02	1.71E-02	6.13E-02	2.45E-01
	Dermal	Adults	3.07E-06	9.08E-07	1.51E-05	6.66E-06	2.46E-03	1.13E-05	2.50E-03
		Children	2.12E-04	6.28E-05	1.05E-03	4.60E-04	1.70E-01	7.80E-04	1.73E-01
	Inhalation	Adults	4.01E-02	1.19E-02	5.93E-01	ND	3.21E+1	4.12E+00	3.69E+01
		Children	8.23E-02	2.43E-02	1.22E+00	ND	6.59E+02	8.46E+00	7.56E+01
Yenagoa	Ingestion	Adults	8.83E-03	ND	ND	1.39E-02	3.41E-03	1.05E-02	3.66E-02
		Children	7.25E-02	ND	ND	1.14E-01	2.79E-02	8.63E-02	3.01E-01
	Dermal	Adults	3.73E-06	ND	ND	9.77E-06	4.03E-03	1.59E-05	4.06E-03
		Children	2.58E-04	ND	ND	6.76E-04	2.79E-01	1.10E-03	2.81E-01
	Inhalation	Adults	4.87E-02	ND	ND	ND	5.27E+01	5.80E+00	5.85E+01
		Children	9.99E-02	ND	ND	ND	1.08E+02	1.19E+01	1.20E+02
Eneka	Ingestion	Adults	6.23E-03	2.30E-05	1.15E-02	3.28E-03	8.10E-04	3.19E-03	2.50E-02
		Children	5.11E-02	1.88E-04	9.42E-02	2.69E-02	6.62E-03	2.62E-02	2.05E-01
	Dermal	Adults	2.63E-06	2.91E-06	4.85E-05	2.31E-06	9.50E-04	4.82E-06	1.02E-03
		Children	1.82E-04	2.01E-04	3.35E-03	1.60E-04	6.60E-02	3.30E-04	7.02E-02
	Inhalation	Adults	3.44E-02	3.79E-02	1.90E+00.	ND	1.25E+01	1.76E+00	1.62E+01
		Children	7.05E-02	7.79E-02	3.89E+00	ND	2.56E+01	3.61E+00	3.32E+01
Oyigbo	Ingestion	Adults	ND	4.99E-06	2.49E-03	2.02E-02	4.22E-03	ND	2.69E-02
		Children	ND	4.09E-05	2.05E-02	1.66E-01	3.46E-02	ND	2.21E-01
	Dermal	Adults	ND	6.32E-07	1.05E-05	1.42E-05	4.99E-03	ND	5.01E-03
		Children	ND	4.37E-05	7.30E-04	9.84E-04	3.45E-01	ND	3.47E-01
	Inhalation	Adults	ND	8.25E-03	4.12E-01	ND	6.52E+01	ND	6.56E+01
		Children	ND	1.69E-02	8.46E-01	ND	1.34E-02	ND	1.35E+02
Woji	Ingestion	Adults	2.34E-02	1.12E-05	5.61E-03	8.95E-03	1.75E-03	8.49E-03	4.82E-02
		Children	1.92E-01	9.21E-05	4.60E-02	7.34E-02	1.43E-02	6.97E-02	3.95E-01
	Dermal	Adults	9.87E-06	1.42E-06	2.37E-05	6.30E-06	2.06E-03	1.28E-05	2.12E-03
		Children	6.83E-04	9.83E-05	1.64E-03	4.36E-04	1.43E-01	8.90E-04	1.47E-01
	Inhalation	Adults	1.29E-01	1.86E-01	9.28E-01	ND	2.70E+01	4.68E+00	3.27E+01
		Children	2.64E-01	3.81E-02	1.90E+00	ND	5.53E-01	9.61E+00	6.71E+01
Eleme	Ingestion	Adults	1.71E-02	1.94E-05	9.71E-03	7.23E-03	1.80E-04	5.61E-02	3.99E-02
		Children	1.41E-01	1.59E-04	7.97E-02	5.94E-02	1.51E-03	4.60E-02	3.27E-01
	Dermal	Adults	7.24E-06	2.46E-06	4.10E-05	5.09E-06	2.20E-04	8.46E-06	2.81E-04
		Children	5.01E-04	1.70E-04	2.84E-03	3.52E-04	1.50E-02	5.90E-04	1.95-E02
	Inhalation	Adults	9.45E-02	3.21E-02	1.61E+00	ND	2.84E+00	3.09E+00	7.66E+00
		Children	1.94E-01	6.59E-02	3.30E+00	ND	5.82E+00	6.35E+00	1.57E+01
Control Site 1	Ingestion	Adults	ND	2.15E-05	1.08E-02	2.36E-03	4.80E-04	2.18E-02	1.58E-02
		Children	ND	1.76E-04	8.82E-02	1.93E-02	3.95E-03	1.79E-02	1.30E-01
	Dermal	Adults	ND	2.72E-06	4.54E-05	1.66E-06	5.70E-04	3.29E-06	6.22E-04
		Children	ND	1.88E-04	3.14E-03	1.15E-04	3.93E-02	2.30E-04	4.30E-02
	Inhalation	Adults	ND	3.56E-02	1.78E+00	ND	7.42E+00	1.20304	1.04E+01

		Children	ND	7.30E-02	3.65E+00	ND	1.52E+01	2.47E+00	2.14E+01
Control Site 2	Ingestion	Adults	ND	1.01E-05	5.04E-03	4.16E-03	3.60E-04	ND	9.57E-03
		Children	ND	8.27E-05	4.13E-02	3.41E-02	2.96E-03	ND	7.85E-02
	Dermal	Adults	ND	1.28E-06	2.13E-05	2.93E-06	4.30E-04	ND	4.52E-04
		Children	ND	8.83E-05	1.47E-03	2.03-04	2.95E-03	ND	3.12E-02
	Inhalation	Adults	ND	1.67E-02	8.34E-02	ND	5.57E+00	ND	6.42E+00
		Children	ND	342E-02	1.71E+00	ND	1.14E+01	ND	1.32E+01

4.2. Risk assessment of borehole water

The carcinogenic and non-carcinogenic risk assessment was conducted using two exposure pathways (ingestion and dermal) for borehole water samples.

4.2.1. Carcinogenic Risk assessment for adults and children

(Figure 8 and 9) shows the carcinogenic chronic daily intake (CDI) of heavy metals conducted for adults and children. The CDI values for adults and children ranged from As: (nd ; nd), Cr (1.34E-10 – 3.50E-08; 5.13E-11 – 2.79E-08), Cu (1.11E-11 – 8.75E-10 ; 4.27E-12 – 6.98E-10); Ni (nd ; nd). (Table 8) shows the cancer risk calculation across ingestion and dermal pathways. Using USEPA acceptable limit as a guideline, the values are well below the limit, and so there is no appreciable risk associated.

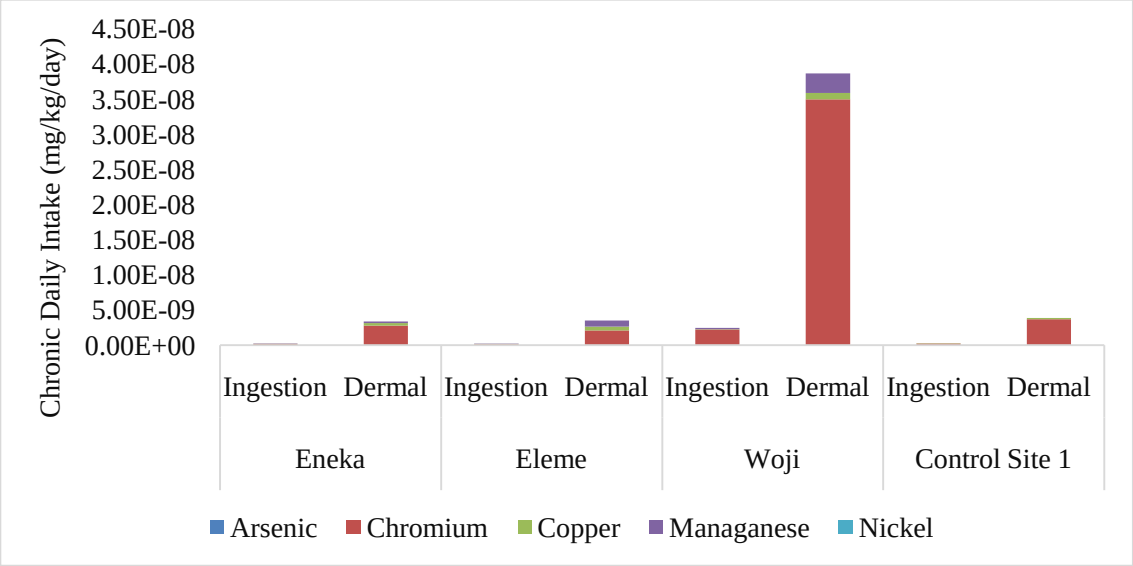

Figure 8: CDI for carcinogens in heavy metals for adults

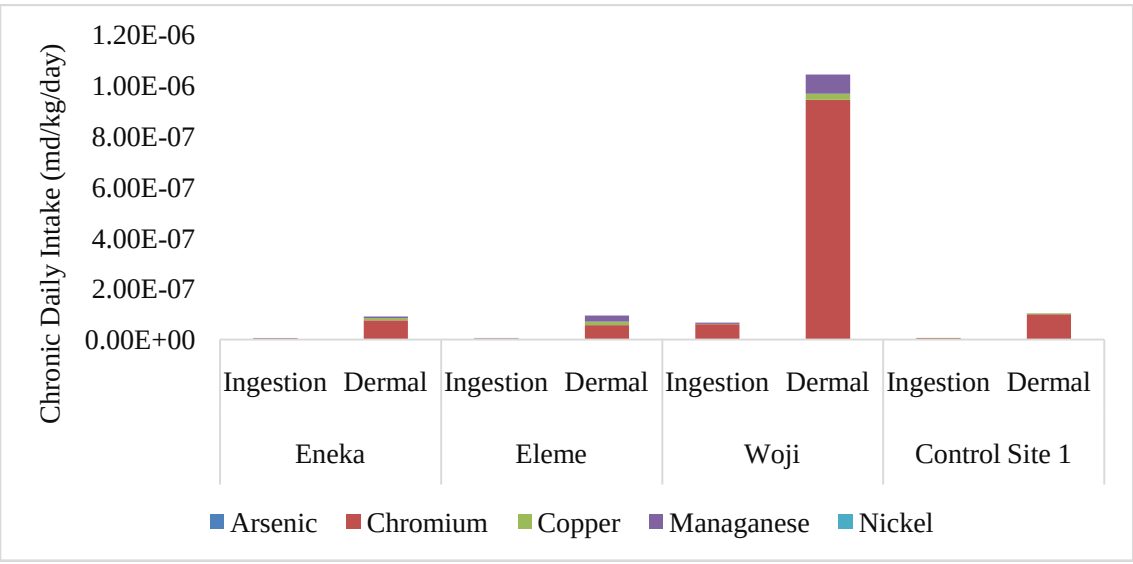

Figure 9: CDI for carcinogens in heavy metals for children

Table 8: Cancer risk of heavy metals across different pathways for adults and children

Location	Exposure pathway	Recipient	As	Cr-III	Cr-VI	Σ-Heavy metals
Eneka	Ingestion	Adults	ND	8.90E-11	8.90E-11	1.78E-10
		Children	ND	3.42E-11	3.42E-11	6.84E-11
	Dermal	Adults	ND	ND	ND	ND
		Children	ND	ND	ND	ND
Eleme	Ingestion	Adults	ND	6.86E-11	6.68E-11	1.34E-10
		Children	ND	2.56E-11	2.56E-11	5.13E-11
	Dermal	Adults	ND	ND	ND	ND
		Children	ND	ND	ND	ND
Woji	Ingestion	Adults	ND	1.11E-09	1.11E-09	2.23E-09
		Children	ND	4.27E-10	4.27E-10	8.55E-10
	Dermal	Adults	ND	ND	ND	ND
		Children	ND	ND	ND	ND
Control Site 1	Ingestion	Adults	ND	1.17E-10	1.17E-10	2.34E-10
		Children	ND	4.49E-11	4.49E-11	8.98E-11
	Dermal	Adults	ND	ND	ND	ND
		Children	ND	ND	ND	ND

4.2.2. Non-carcinogenic Risk assessment for adults and children

(Figure 10 and 11) illustrates the non-carcinogenic chronic daily intake (CDI) of heavy metals conducted for adults and children. The CDI values for adults and children ranged from As: (nd ; nd), Cr (3.60E-09 – 9.42E-07; 5.98E-09 – 3.26E-06), Cu (3.00E-10 – 2.36E-08 ; 4.99E-10 – 8.14E-08); Ni (nd ; nd).

The hazard index of heavy metals conducted using chronic daily intake were shown in (Table 9). The hazard index (cumulative heavy metals) were below one (1), and so there is no associated health risk to recipient (adults and children).

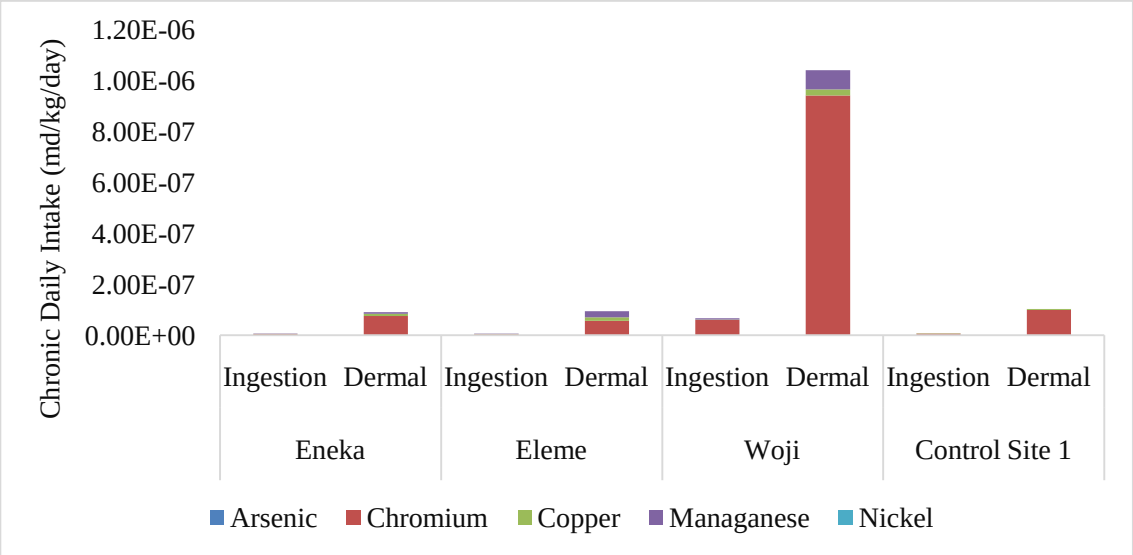

Figure 10: CDI non-carcinogen in heavy metals for adults

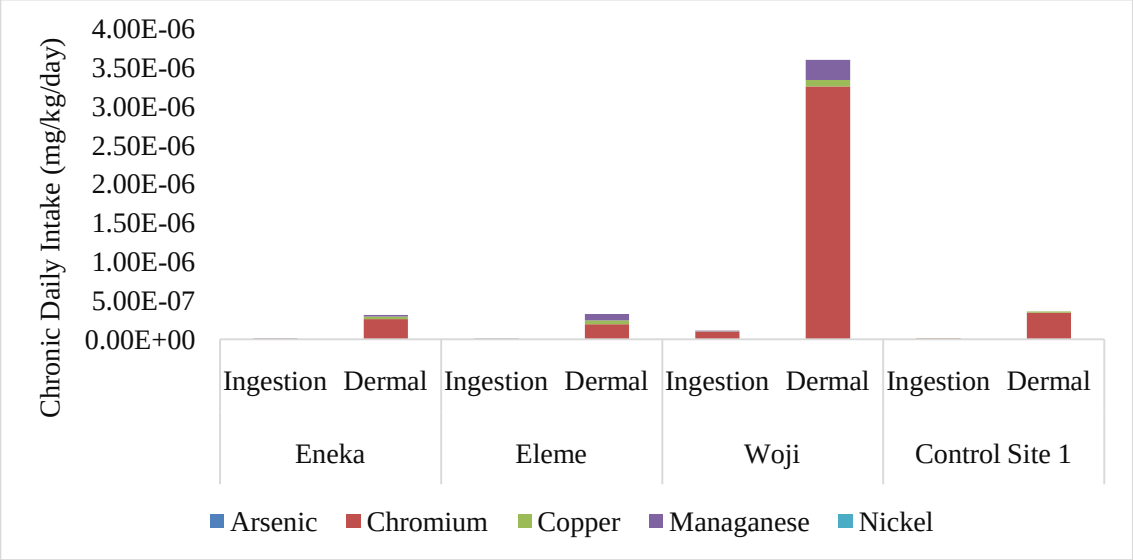

Figure 11: CDI non-carcinogen in heavy metals for children

Table 9: Hazard Index of heavy metals for adults and children

Location	Exposure pathway	Recipient	As	Cr-III	Cr-VI	Cu	Mn	Ni	Σ-Heavy metals
Eneka	Ingestion	Adults	ND	3.20E-09	1.60E-06	1.50E-08	2.57E-09	ND	1.62E-06
		Children	ND	5.32E-09	2.66E-06	2.49E-08	4.27E-09	ND	2.69E-06
	Dermal	Adults	ND	1.51E-05	2.51E-04	3.93E-07	1.13E-04	ND	3.80E-04
		Children	ND	5.21E-05	8.68E-04	1.36E-06	3.91E-04	ND	1.31E-03
Eleme	Ingestion	Adults	ND	2.49E-09	1.20E-06	2.25E-08	1.07E-08	ND	1.23E-06
		Children	ND	3.99E-09	1.99E-06	3.74E-08	1.78E-08	ND	1.31E-03
	Dermal	Adults	ND	1.13E-05	1.88E-08	5.87E-07	4.71E-04	ND	6.71E-04
		Children	ND	3.91E-05	6.51E-04	2.03E-06	1.63E-03	ND	2.32E-03
Woji	Ingestion	Adults	ND	4.0E-08	2.0E-05	3.75E-08	3.42E-08	ND	2.01E-05
		Children	ND	6.55E-08	3.32E-05	6.23E-08	5.70E-08	ND	3.34E-05
	Dermal	Adults	ND	1.88E-04	3.14E-03	9.81E-07	1.51E-03	ND	4.84E-03
		Children	ND	6.51E-04	1.09E-02	3.39E-06	5.21E-03	ND	1.67E-02
Control Site 1	Ingestion	Adults	ND	4.20E-09	2.10E-06	7.49E-09	ND	ND	2.11E-06
		Children	ND	6.69E-09	3.49E-06	1.25E-08	ND	ND	3.51E-06
	Dermal	Adults	ND	1.98E-05	3.30E-04	1.96E-07	ND	ND	3.50E-04
		Children	ND	6.84E-05	1.14E-03	6.78E-07	ND	ND	1.21E-03

4.3. Cumulative cancer risk and hazard index of soil and borehole water

(Table 10) shows the cumulative cancer risk and hazard index of both soil and borehole water sources. Cumulative cancer risk were within USEPA acceptable limits across both soil and borehole water sources, thus, no associated cancer risk will be realised [29, 55]. As presented, Soils sources showed that hazard index was above one (1) across all locations for both adults and children compared to borehole water that was less than one (1). This indicates less significance for borehole consumption or dermal contact [50], as regards soil source, inhalation of particulates is the major contributors compared to accidental ingestion of soil or skin contact. Children exposed to waste dumps are at high risk from respiratory issues over long period [5]. The degree of toxicity of heavy metals to human health is directly related to the daily intake from varying exposure pathways (ingestion, dermal contact and inhalation) in the study areas. Arsenic, Copper, Chromium, Manganese, Nickel are known to cause probable health impact such as gastrointestinal respiratory diseases, diabetes, blood diseases, skeletal defect, paralysis, cardiovascular diseases, Alveolar congestion, Endocrine disruption. Even though there is concern over the potential health risk of the local residents, most especially the children living close to dumpsite areas due to the possibility of dispersal of heavy metals to the entire environment and as well inherent hand to mouth activities leading to long life exposure and resident's detrimental health.

Table 10: Total cancer risk and non-cancer risk of heavy metals across soil and borehole water sources

		Soil source		Borehole water source	
Location	Recipient	Total Cancer Risk	Hazard Index	Total Cancer Risk	Hazard Index
Eliozu	Adults	7.73E-06	3.69E+01	NA	NA
	Children	2.55E-06	7.60E+01	NA	NA
Yenagoa	Adults	1.81E-07	5.85E+01	NA	NA

	Children	2.86E-07	1.21E+02	NA	NA
Eneka	Adults	1.81E-07	1.62E+01	1.78E-10	3.82E-04
	Children	2.34E-06	3.35E+01	6.84E-11	1.31E-03
Oyigbo	Adults	5.07E-06	1.62E+01	NA	NA
	Children	1.78E-06	3.35E+01	NA	NA
Woji	Adults	1.24E-05	3.28E+01	2.23E-09	4.86E-03
	Children	5.93E-06	1.36E+02	8.55E-10	1.67E-02
Eleme	Adults	2.52E-05	7.70E+00	1.34E-10	6.72E-04
	Children	8.63E-05	1.60E+01	5.13E-11	3.63E-04
Control Site 1	Adults	2.18E-05	1.04E+01	2.34E-10	3.52E-04
	Children	7.67E-06	2.16E+01	8.98E-11	1.21E-03
Control Site 2	Adults	1.02E-05	6.43E+00	NA	NA
	Children	3.59E-06	1.33E+01	NA	NA

IV. Conclusion

Heavy metal pollution of the environment, even at low levels and their resulting long-term cumulative health effects are among the leading health concerns all over the world. The study investigated the concentration and carcinogenic health risk of selected heavy metals from soil and borehole water samples in selected active dumpsites in South-South Nigeria. The heavy metal concentrations in soil samples were observed in order of Cu>Mn>Ni>Cr>As (Eleme), Cu>Mn>As>Ni>Cr (Eliozu), Cu>Mn>Ni>Cr>As (Eneka), Cu>Mn>Cr (Oyigbo), Cu>Mn>Ni>Cr>As (Woji), Cu>Ni>Cr>Mn>As (Yenagoa), Cu>Mn>Ni>Cr (Control Site 1) and Cu>Mn>Cr (Control site 2). For borehole water samples, As and Ni were not detected across Eneka, Eleme, Woji and Control Site 1. The results showed that the concentrations of some heavy metals detected were within WHO acceptable limits. The results of health risk of soil samples indicated that inhalation pathway was the greatest contributor to the chronic daily intake followed by the ingestion and dermal contact. For borehole water source, dermal was highest, while ingestion least. Hazard index (HI) values were above one (1) for soil samples, while HI values was least than one (1), but cancer risk were between USEPA acceptable limits. This shows that prolonged exposure to soil from waste dumpsites can lead to detrimental health impact for children compared to adults. Therefore, individuals living within the vicinity of the dumpsites should bear in mind the health consequences. Government interventions are advised to remediate the environmental and health issues that may happen to underground water sources from prolong waste dumping without adequate isolation mechanisms.

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