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Evaluating the Levels and Human Health Risks of Heavy Metals in Soils around Onne Landfill, Rivers State, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author PA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author RAW managed the analyses and the literature searches of the study. Both authors read and approved the final manuscript.

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ABSTRACT

This study evaluated selected heavy metals' levels in soil around the landfill in Onne Rivers State, Nigeria. It also examines potential human health risks due to exposure to the contaminated soil. Composite samples of soils from the northern, southern, eastern and western domains of the landfill were collected, processed, and analysed for heavy metals using atomic absorption spectrophotometry, and their human health risks were evaluated. The heavy metals' levels in the soils around the four domains were in the order Pb>Cr>Ni>Cd>As. Children and adult ingestion, inhalation and dermal hazards quotients for the selected metals in the four domains were below unity ranging from {($HQ_{children}$ 2.71 x 10^{-10} As inhalation in the eastern domain to 9.24 x 10^{-1} Pb ingestion in the northern domain); HQ_{adult} 1.55 x 10^{-10} As inhalation in the eastern domain to 9.90 x 10^{-2} Pb ingestion in the northern domain)}. Adult ingestion, inhalation and dermal cancer risks (CR_{adult}) were within acceptable limits, ranging from 1.99 x 10^{-13} As inhalation in the eastern domain to 4.68 x10^{-5} Cr ingestion in the northern domain. However, ingestion cancer risk for children ($CR_{children}$) due to exposure to Ni and Cr in the four domains were above tolerable limit ranging from {(Ni - 2.00 x 10^{-4} in the southern domain to 3.11 x 10^{-4} in the northern domain); Cr – 2.95 x 10^{-4} in

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the southern domain to 4.37 x 10^{-4} in the northern domain)}. Children and adult hazards index due to exposure to the selected metals were also less than 1.0, ranging from children exposure to Ni (5.91 x 10^{-3}) in the southern domain and Pb (9.25 x 10^{-1}) in the northern domain to adult exposure to Ni (6.50 x 10^{-4} in the southern domain and Pb (9.94 x 10^{-2}) in the northern domain. Total cancer risks (TCR_{adult}) due to adult exposure to the metals were within tolerable limit, ranging from Cd (4.93 x 10^{-7}) in the southern domain to Cr (5.01 x 10^{-5}) in the northern domain. And total cancer risk ($TCR_{children}$) due to children exposure to Ni and Cr were above tolerable limit, ranging from {Ni (2.40 x 10^{-4} in the southern domain to 3.74 x 10^{-4} in the northern domain); Cr (3.54 x 10^{-4} in the southern domain to 5.24 x 10^{-4} in the northern domain)}. The values for both non carcinogenic and carcinogenic risks were higher for children than those for adult. Reasons for this attributes and improvement actions were suggested.

Keywords: Heavy metals; landfill; contaminants; health risks; hazard quotient; cancer risk.

1. INTRODUCTION

Urban areas throughout the world are experiencing rapid change as a result of both urbanization and accelerated development of the social economy [1,2]. As a consequence, there is a decline in the quality of urban environment [3].

Public concerns and awareness regarding environmental protection have grown world-wide. This is also reflected in the development of environmental legislation in different countries to address and guide sustainable environmental management in all areas [4]. However, lack of planning and facilities in developing countries such as Nigeria, particularly in Onne, to detect and monitor soil, stream sediment and water quality could expose the citizens to health risks from pollutants including heavy metals [5,6,7].

Waste material is an unavoidable by-product of human activities. Economic development, urbanization and improved living standards in cities increase the quantity and complexity of generated solid waste. Improper management of the waste could lead to degradation of urban environment, puts strain on natural resources and leads to health problems.

Sustainable waste management implies that wastes are managed by prioritizing with regards to the hierarchy of wastes [4]. The waste management hierarchy positioned waste reduction at the topmost priority if possible. The other priorities are reuse, recovery, recycling, composting and energy, and treatment and disposal which also includes landfilling. Most of the wastes produced in Onne town and environ are generally disposed via landfills. Waste disposal to landfills (or dumpsites), in general, is an easy and low-cost waste management option and it is an environmentally acceptable method for municipal solid waste on ground, but it does raise environmental concerns if it is not properly managed. During the process of waste degradation, landfills produce waste products in three phases: these are solids (degraded waste), liquids (leachate, which is water polluted with wastes), and gas (usually referred to as landfill gas) [8].

One of the most important properties of heavy metals which differentiate them from other toxic pollutants is that they are not biodegradable in the environment [9]. Another problem associated with them is the potential for bioaccumulation and biomagnifications causing heavier exposure for organisms that are present in the environment. Toxic metals accumulate in organisms as a result of direct uptake from surrounding across the body walls, from respiration and from food [10]. These pollutants can therefore have a direct influence on human health because they can be transferred into the human body by different pathways, e.g., inhalation, ingestion, and dermal absorption [11].

The degree of toxic metal contaminations in soil can pose hidden dangers to human health via these different pathways (e.g., oral ingestion pathway, inhalation pathway and dermal contact pathway) [12, 13]. Studies have shown that toxicity of exposure to these contaminants is influenced by numerous factors, including the route of exposure, absorption, metabolism and distribution in the human body [14,15]. Furthermore, a person's age is also a significant factor that should be given more consideration. Children and infants are more likely to be affected compared with adults, because of their behavioral characteristics (e.g., outdoor activities, mouthing non-food objects, and sucking their hands or fingers) and are at greater risk of exposure to contaminants in soils [15,16].

Furthermore, landfills and their aforesaid wastes products may pollute the three principal environmental media – atmosphere, the lithosphere and the hydrosphere. Such pollution will be transmitted through these media and will have an impact, either directly or indirectly, upon human, the natural environment (including aquatic and terrestrial flora and fauna) and the built environment. Landfills located at the periphery of cities are, knowingly or not, frequently converted to residential development as a result of the pressure of increasing urban population. This highly necessitate that risks of landfills be assessed and managed to guard the environment and species from landfill hazards. The soil is therefore a valuable medium for characterizing urban environmental quality [3] and therefore the health of humans.

In dry seasons, soil in the landfill will be dry and hence generate dust. The dusts may also contribute to air pollution via resuspension [17]. Therefore, they might pose a health risk to the population inhabiting the area [18]. The composition of dust in urbanized areas has been investigated intensively by many researchers around the world [19,20,21,22,23,24]. This study evaluates the levels and human health risks of some selected heavy metals in soils around Onne landfill site.

2. MATERIALS AND METHODS

2.1 Study Area and Sample Collection

Top soil (0 - 20 cm) subsamples were collected using stainless steel hand trowel at different points around the landfill and composited in a labelled sealed polyethylene package (soil sample were taken 30 m North, 30 m South, 30 m east and 30 m West of the landfill) and immediately taken to the laboratory for further analysis. The sampling site is located within latitude 4^{o} 43’ 0” North and longitude 7^{o} 9’ 0” East. The Map of the sampling site is shown in Fig. 1.

2.2 Analysis of Physico-Chemical Attributes and Heavy Metals

The composited samples were air-dried in the laboratory, finely powdered with the use of porcelain mortar and sieved to < 2 mm and then homogenized before analysis. Standard procedures were employed to determine physicochemical attributes of the soil. Atomic absorption spectrophotometer (AAS) was used to determine the concentrations of Cd, Ni, Pb, As and Cr. 5 g of each of the sieved soil sample was digested in aqua regia (HCl/HNO3, 3:1 v/v) in a 95^{o}C water bath for 2 h. Quality assurance and quality control (QA/QC) were conducted by using reagent blanks, replicates, and standard reference materials (GBW07427). The soil texture triangle in Fig. 2 was used to determine the soil samples textural classes.

2.3 Human Health Risks

Human exposure and health risk assessment is a process of estimating the possibility that humans who may be exposed to contaminants in the environment now or in the future will experience negative health effects and the nature and severity of the adverse health effect. Human health risk indices determined were hazard quotient and cancer risks. The hazard quotient (HQ) for metals with non-carcinogenic effects and cancer risk (CR) for metals with carcinogenic effects, were calculated based on their corresponding chronic daily intake (CDI), reference dose (RfD), and slope factor (SF) values in accordance with the models described by [26,27]. Metal toxicological characteristics used in this study were those reported by [27,28,29,30,31,32].

To calculate the hazard quotient (HQ), the CDI for each element and exposure pathway was divided by the corresponding reference dose, (equation 1) for systemic toxicity. For carcinogens the CDI is multiplied by the corresponding slope factor to produce a level of excess lifetime cancer Risk (Equation 2).

Table 1. The toxicities of selected heavy metals

Metals	Toxicities
Cd	Kidney damage, renal disorder, and human carcinogen
Pb	Damage the fetal brain; diseases of the kidneys, circulatory system, and nervous system
Ni	Dermatitis, nausea, chronic asthma, coughing, and human carcinogen
As	Skin manifestations, visceral cancers, and vascular disease
Cr	Headache, diarrhea, nausea, vomiting, and carcinogenic

Source: [25]

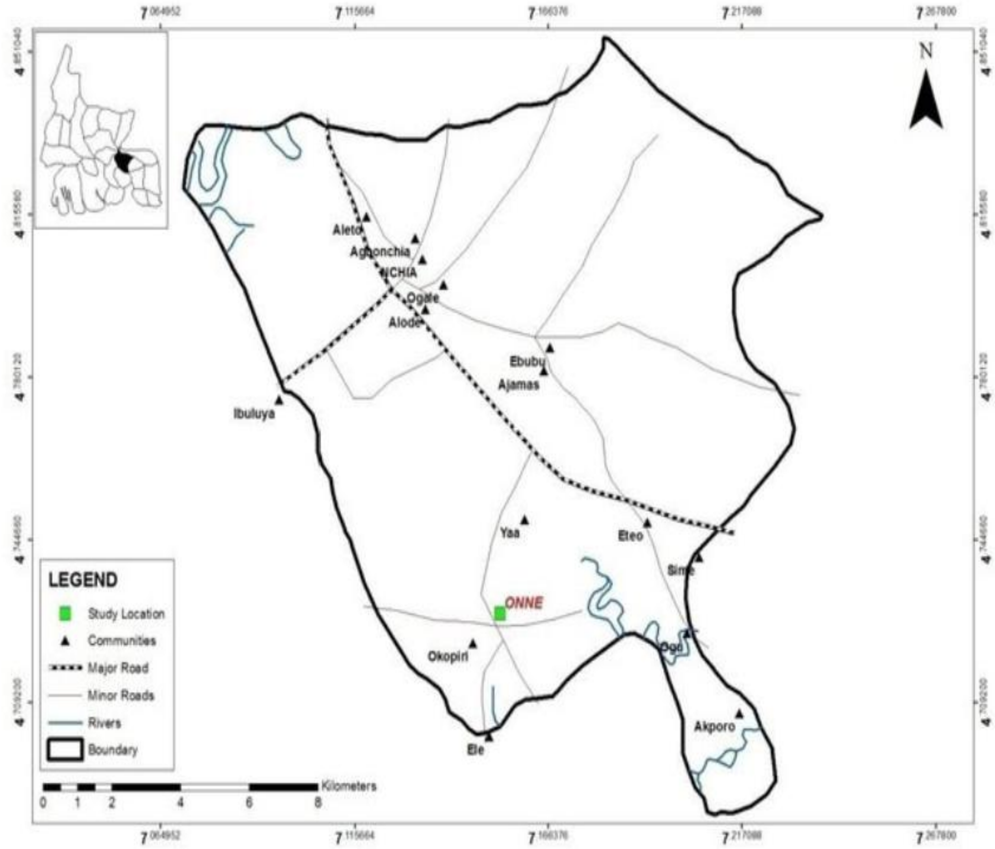

Fig. 1. Map of Rivers State indication the study area –Onne

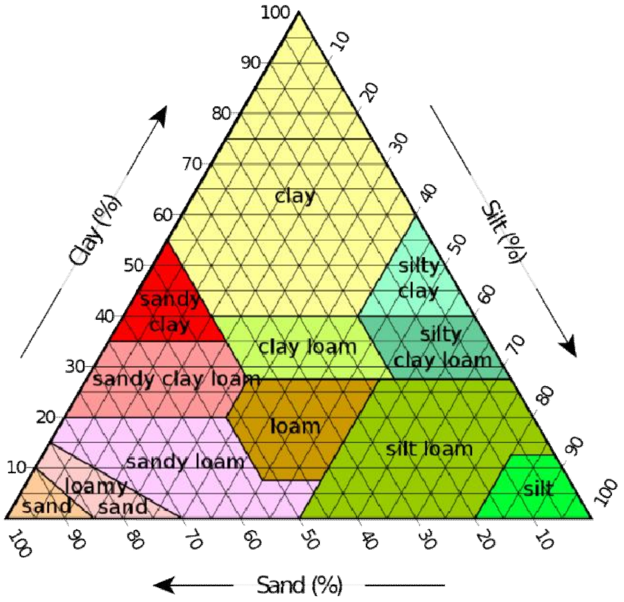

Fig. 2. Triangle of soil texture used to classify the soil sample

$$HQ = \frac{CDI}{RfD} \tag{1}$$

$$CR = CDI \times SF \tag{2}$$

Though interactions between some metals might result in their synergistic manner [13], it was assumed that all the metal risks are additive, hence it was possible to calculate the cumulative non-carcinogenic hazard expressed as the Hazard Index (HI), (Equation 3), and carcinogenic risk expressed as the total cancer risk (Equation 4).

$$\begin{aligned} HI &= \sum HQ = HQ_{ing} + HQ_{inh} + HQ_{dermal} \\ &= \frac{CDI_{ing-nc}}{RfD_{ing}} + \frac{CDI_{inh-nc}}{RfC_{inh}} + \frac{CDI_{dermal-nc}}{RfD_{dermal}} \\ &= \frac{CDI_{ing-nc}}{RfD_{ing}} + \frac{CDI_{inh-nc}}{RfC_{inh}} + \frac{CDI_{dermal-nc}}{RfD_{ing}\ X\ ABS} \end{aligned} \tag{3}$$

$$\begin{aligned} TCR &= \sum CR = CR_{ing} + CR_{inh} + CR_{dermal} \\ &= CDI_{ing-ca}\ X\ SF_{ing} + CDI_{inh-ca}\ X\ IUR + \frac{CDI_{dermal-ca}\ X\ SF_{ing}}{ABS} \end{aligned} \tag{4}$$

The greater is the value of HQ and total hazard index (THI) above 1, the greater is the level of concern since the accepted standard is 1.0 at which there will be no significant health hazard [33,34]. The probability of experiencing long-term health hazard effects increases with the increasing HI value [35,36]. The description of parameters and their values used in this assessment are presented in Table 2.

Table 2. Description of Parameters and Values Used in Human Health Risk Assessment

Parameters	Name	Units	Value
C_{exp}	Concentration of the trace element	mg/kg	Element dependent
R_{ing}	Ingestion rate	mg/day	200 for children, 100 for adults
EF	Exposure frequency	days/year	40 for recreational
ED	Exposure duration	years	6 for children, 24 for adults
BW	Body weight	Kg	15 for children, 70 for adults
AT	Averaging time	days	ED X 365
R_{inh}	Inhalation rate	m^3/day	7.5 for children, 20 for adults
PEF	Particle emission factor	m^3/day	1.36×10^9
SA	Exposed skin area	cm^2/day	2800 for children, 5700 for adults
SAF	Skin adherence factor	mg/cm^2	0.2 for children, 0.07 for adults
ABS	Dermal absorption factor		0.001 for non-carcinogenic, 0.01 for carcinogenic
IUR	Chronic inhalation unit risk	$(\mu g\ m^{-3})^{-1}$	

Source: [26]

3. RESULTS AND DISCUSSION

3.1 Results

The results of physico-chemical analysis of soil samples from the four domains of Onne landfill are presented in Table 3. The results of human health risk assessments are presented in Tables 4 to 8.

3.2 Discussion

3.2.1 Physicochemical attributes

Table 3 indicated the physicochemical attributes for the soil samples from northern, southern, eastern and western sides of the landfill. The table revealed pH range from 5.58 ± 0.000 to 6.20 ± 0.141. The northern side has the highest pH, while the southern side has the lowest pH values. The pH range implies that the soil around the landfill is mildly acidic. This result is relatively lower than the pH value (7.20 ± 0.10) reported by [37], but compared favourably with the mean pH value (6.4) reported by [38] in similar studies. pH is an important soil parameter because it influences solute concentrations and sorption of contaminants in the soil. High pH values reduce availability and mobility of some PTMs in the soil and low pH values usually favour distribution and transport of PTMs in soil. Except for the soil sample from the northern axis, the pH values of the other samples fall slightly below the favourable pH condition (6.2 – 7.5) that enhances availability of nutrients for most plants. The lower pH range may enhance leaching of heavy metals in the soil.

Table 3 shows that the specific conductivity (µScm^{-1}) of the soil samples were in the range 358.00 ± 1.414 to 371.00 ± 1.414. The lowest value was obtained for soil samples taken from the south, while the highest value was obtained for soil samples taken from the north. The conductivity values obtained in this work were lower than the value (820.00 ± 2.0) reported by [37], but higher than the value (142.00 µScm^{-1}) reported by [39] in similar studies. Conductivity is an important soil attribute as it indicates the presence of harmful salts in the soil resulting from low rainfall and high evaporation.

Another vital constituent of soil resource base is the soil organic matter (SOM), it influences the physico-chemical and biological activities of the soil and, therefore has a wide-range of roles to play with regards to fertility, crop productivity and sustainable agriculture, it differ with climate, soil type and farming system [40]. Organic matter (%) in the soil samples as shown in Table 3, were in the range 4.20 ± 0.000 to 5.60 ± 0.000. Organic matter of top soil is usually in the range of 1% to 6% [41], hence the values of the SOM in the samples compare favourably.

Table 3 shows the results of bulk density (gcm^{-3}) obtained for the samples under study were in the range 1.62 ± 0.014 to 1.65 ± 0.014. The soil sample from the north has the highest value and samples from east and south have lowest values. Bulk density gives the level compaction of soil. It reflects the soil's ability to function for structural support, water and solute mobility, and soil aeration. The ideal soil bulk density for plant growth in a sandy soil such as the type of soil obtainable at the sampling sites should be less than 1.6 gcm^{-3} and root growth is prohibited as bulk density increases to 1.8 gcm^{-3} [42].

Soil texture as an important soil attribute influences rate of infiltration of storm-water. The percentage of sand, clay and silt determines the textural class of a soil. The values obtained in the work (Table 3) showed that the soil sample is loamy sand.

Table 3 also shows that the cation exchange capacity (meq/100g) obtained for the study area are in the range 3.46 ± 0.028 to 3.72 ± 0.000. The cation exchange capacity of soil is the maximum amount of cations that 100 g of dry soil can absorb [43]. It is the ability of the soil to react with positively charged molecules. It refers to how well colloidal materials of soils are able to give off the ions surrounding their negatively charged surface for other highly positively charged ions from a solution system that these particles swim in [44]. The higher the CEC, the higher the negative charge of the soil and the more cations that can be held. It is the total capacity of a soil to hold exchangeable cations. CEC is a critical component of soil properties influencing soil structure stability, nutrient availability, pH and soil's reaction to amelioration procedures, and hence it does regulate the movement of heavy metals in soil [45]. It has been reported [37] that CEC increases with increasing pH and soils with a higher clay fraction tends to have a higher CEC. The results in this study compare favourably.

The concentration of Cd (mg/kg) in the soil samples taken from the west, east, north and south of the landfill were 1.28 ± 0.014, 1.24 ± 0.028, 3.09 ± 0.000 and 1.00 ± 0.000,

Table 3. Physico-chemical attributes of soil samples from Onne landfill

Parameters	West		East		North		South	
pH	5.80^{ab}	±0.141	5.91^{ab}	±0.000	6.20^{a}	±0.141	5.58^{b}	±0.000
Conductivity (µs/cm)	368.00^{a}	±0.000	370.00^{a}	±0.000	371.00^{a}	±1.414	358.00^{b}	±1.414
Organic matter (%)	4.3.00^{c}	±0.001	4.5.00^{b}	±0.001	5.6.00^{a}	±0.000	4.2.00^{d}	±0.000
Bulk density	1.64^{a}	±0.000	1.62^{a}	±0.014	1.65^{a}	±0.014	1.62^{a}	±0.028
Sand (%)	89.21^{a}	±0.000	89.30^{a}	±0.283	89.12^{a}	±0.000	88.95^{a}	±0.042
Clay (%)	7.10^{a}	±0.000	6.70^{ab}	±0.141	6.60^{b}	±0.000	6.70^{ab}	±0.141
Silt (%)	5.23^{a}	±0.000	4.86^{b}	±0.042	4.28^{c}	±0.000	4.87^{b}	±0.028
CEC (meq/100g)	3.72^{a}	±0.000	3.58^{b}	±0.014	3.46^{c}	±0.028	3.54^{bc}	±0.028
Cadmium, Cd (mg/kg)	1.28^{b}	±0.014	1.24^{b}	±0.028	3.09^{a}	±0.000	1.00^{c}	±0.000
Lead, Pb (mg/kg)	154.14^{c}	±0.057	125.37^{d}	±0.028	285.45^{a}	±0.000	180.25^{b}	±0.071
Nickel, Ni (mg/kg)	14.29^{b}	±0.000	12.17^{c}	±0.000	16.17^{a}	±0.028	10.37^{d}	±0.000
Arsenic, As (mg/kg)	0.28^{c}	±0.028	0.26^{c}	±0.000	0.87^{a}	±0.000	0.43^{b}	±0.028
Chromium, Cr(mg/kg)	65.24^{b}	±0.057	55.27^{c}	±0.000	77.17^{a}	±0.028	52.16^{d}	±0.000
Texture Class	Loamy sand		Loamy sand		Loamy sand		Loamy sand	

Values are mean ± SD of triplicate samples; ^{abc}Mean value bearing different superscripts in the same row differ significantly ($P<0.05$)

Table 4. Hazard quotients and cancer risks of contaminants in soil sample from the northern side of the Onne landfill

Entry route	Contaminant	$HQ_{Children}$	HQ_{Adult}	$CR_{Children}$	CR_{Adult}
Ingestion	Cd	3.50×10^{-2}	3.75×10^{-3}	1.33×10^{-5}	1.42×10^{-6}
	Pb	9.24×10^{-1}	9.90×10^{-2}	2.75×10^{-5}	2.94×10^{-6}
	Ni	9.16×10^{-3}	9.81×10^{-4}	3.11×10^{-4}	3.34×10^{-5}
	As	3.28×10^{-2}	3.52×10^{-3}	1.48×10^{-5}	1.58×10^{-6}
	Cr	2.18×10^{-1}	2.34×10^{-2}	4.37×10^{-4}	4.68×10^{-5}
Inhalation	Cd	9.65×10^{-5}	5.51×10^{-5}	1.74×10^{-12}	9.92×10^{-13}
	Pb	6.37×10^{-4}	3.64×10^{-4}	1.07×10^{-12}	6.11×10^{-13}
	Ni	5.61×10^{-5}	3.21×10^{-5}	1.31×10^{-12}	7.50×10^{-13}
	As	9.10×10^{-10}	5.17×10^{-10}	1.17×10^{-12}	6.67×10^{-13}
	Cr	6.02×10^{-7}	3.44×10^{-7}	2.89×10^{-10}	1.65×10^{-10}
Dermal	Cd	1.40×10^{-5}	5.25×10^{-7}	2.66×10^{-6}	9.97×10^{-8}
	Pb	1.23×10^{-3}	4.62×10^{-5}	5.50×10^{-6}	2.06×10^{-7}
	Ni	6.78×10^{-6}	2.54×10^{-7}	6.23×10^{-5}	2.33×10^{-6}
	As	3.28×10^{-8}	1.29×10^{-9}	2.96×10^{-6}	1.11×10^{-7}
	Cr	7.28×10^{-6}	2.73×10^{-7}	8.74×10^{-5}	3.28×10^{-6}

Table 5. Hazard Quotients and Cancer Risks of Contaminants in Soil sample from the Southern side of the Onne landfill

Entry route	**Contaminant**	$HQ_{Children}$	HQ_{Adult}	$CR_{Children}$	CR_{Adult}
Ingestion	Cd	1.13 x 10^{-2}	1.21 x 10^{-3}	4.30 x 10^{-6}	4.61 x 10^{-7}
	Pb	5.83 x 10^{-1}	6.25 x 10^{-2}	1.74 x 10^{-5}	1.86 x 10^{-6}
	Ni	5.87 x 10^{-3}	6.29 x 10^{-4}	2.00 x 10^{-4}	2.14 x 10^{-5}
	As	1.62 x 10^{-2}	1.74 x 10^{-3}	7.30 x 10^{-6}	7.83 x 10^{-7}
	Cr	1.48 x 10^{-1}	1.58 x 10^{-2}	2.95 x 10^{-4}	3.16 x 10^{-5}
Inhalation	Cd	3.12 x 10^{-5}	1.78 x 10^{-5}	5.62 x 10^{-13}	3.21 x 10^{-13}
	Pb	4.02 x 10^{-4}	2.30 x 10^{-4}	6.75 x 10^{-13}	3.86 x 10^{-13}
	Ni	3.60 x 10^{-5}	2.06 x 10^{-5}	8.42 x 10^{-13}	4.81 x 10^{-13}
	As	4.48 x 10^{-10}	2.56 x 10^{-10}	5.77 x 10^{-13}	3.30 x 10^{-13}
	Cr	4.07 x 10^{-7}	2.33 x 10^{-7}	1.95 x 10^{-10}	1.12 x 10^{-10}
Dermal	Cd	4.53 x 10^{-6}	1.70 x 10^{-7}	8.61 x 10^{-7}	3.23 x 10^{-8}
	Pb	7.78 x 10^{-4}	2.92 x 10^{-5}	3.47 x 10^{-6}	1.30 x 10^{-7}
	Ni	4.35 x 10^{-6}	1.63 x 10^{-7}	3.99 x 10^{-5}	1.50 x 10^{-6}
	As	1.62 x 10^{-8}	6.09 x 10^{-10}	1.46 x 10^{-6}	5.48 x 10^{-8}
	Cr	4.92 x 10^{-6}	1.85 x 10^{-7}	5.91 x 10^{-5}	2.22 x 10^{-6}

Table 6. Hazard Quotients and Cancer Risks of Contaminants in Soil sample from the Eastern side of the Onne landfill

Entry route	**Contaminant**	$HQ_{Children}$	HQ_{Adult}	$CR_{Children}$	CR_{Adult}
Ingestion	Cd	1.40 x 10^{-2}	1.50 x 10^{-3}	5.34 x 10^{-6}	5.72 x 10^{-7}
	Pb	4.10 x 10^{-1}	4.35 x 10^{-2}	1.21 x 10^{-5}	1.29 x 10^{-6}
	Ni	6.89 x 10^{-3}	7.38 x 10^{-4}	2.34 x 10^{-4}	2.51 x 10^{-5}
	As	9.81 x 10^{-3}	1.05 x 10^{-3}	4.42 x 10^{-6}	4.73 x 10^{-7}
	Cr	1.56 x 10^{-1}	1.68 x 10^{-2}	3.13 x 10^{-4}	3.35 x 10^{-5}
Inhalation	Cd	3.87 x 10^{-5}	2.21 x 10^{-5}	6.97 x 10^{-13}	3.98 x 10^{-13}
	Pb	2.80 x 10^{-4}	1.60 x 10^{-4}	4.70 x 10^{-13}	2.68 x 10^{-13}
	Ni	4.22 x 10^{-5}	2.41 x 10^{-5}	9.88 x 10^{-13}	5.65 x 10^{-13}
	As	2.71 x 10^{-10}	1.55 x 10^{-10}	3.49 x 10^{-13}	1.99 x 10^{-13}
	Cr	4.31 x 10^{-7}	2.47 x 10^{-7}	2.07 x 10^{-10}	1.18 x 10^{-10}
Dermal	Cd	5.62 x 10^{-6}	2.11 x 10^{-7}	1.07 x 10^{-6}	4.00 x 10^{-8}
	Pb	5.41 x 10^{-4}	2.03 x 10^{-5}	2.41 x 10^{-6}	9.05 x 10^{-8}
	Ni	5.10 x 10^{-6}	1.91 x 10^{-7}	4.69 x 10^{-5}	1.76 x 10^{-6}
	As	9.81 x 10^{-9}	3.68 x 10^{-10}	8.83 x 10^{-7}	3.31 x 10^{-8}
	Cr	5.22 x 10^{-6}	1.96 x 10^{-7}	6.26 x 10^{-5}	2.35 x 10^{-6}

respectively. Cd is significantly used in Ni/Cd batteries, as rechargeables, as corrosion resistance coating to vessels and other vehicles, particularly in high-stress environments such as marine areas. Cd is also used as pigments, stabilizers for polyvinyl chloride (PVC), in alloys and electronic compounds. Wastes related to these materials are continually being disposed in this landfill, and may have been responsible for the high level of Cd in the landfill. Acid rains and the resulting acidification of soil would increase the geochemical mobility of Cd^{2+} and hence plant uptake. Cd is biopersistent and, once absorbed by an organism, remains resident for many years.

The concentration of Pb (mg/kg) were 154.14 ± 0.057, 125.37 ± 0.028, 285.45 ± 0.000 and 180.25 ± 0.071, in the samples taken from the west, east, north and south, respectively. Pb is used in the manufacture of Pb storage batteries, solders, bearings, cable covers, plumbing, paint pigments, and caulking. Waste materials in these categories were sighted in the landfill and may be responsible for the high level of Pb in the soil around the landfill. Pb compounds are predominantly ionic and the general forms of Pb that are released into the soil are Pb(II), lead oxides and hydroxides, and lead-metal oxyanion complexes. Pb is not an essential element and it is well known to be toxic. The most serious source of exposure to soil lead is through direct ingestion (mouthing) of contaminated soil or dust. In general, plants do not absorb or accumulate lead. However, in soils testing high in lead, it is possible for some lead to be taken up. Studies have shown that lead does not readily accumulate in the fruiting parts of vegetable and fruit crops (e.g., corn, beans, squash, tomatoes). Higher concentrations are more likely to be found in leafy vegetables (e.g., lettuce) and on the surface of root crops (e.g., carrots) [46]. Pb is a toxic metal with exceptionally low mobility and high bioavailability. Pb is known to persist in surface soils for a long time [47] and thus, dust is of particular concern in Pb exposure.

The concentration of Ni, As and Cr (mg/kg) in samples taken from west, east, north and south, respectively were 14.29 ± 0.000, 0.28 ± 0.028, 65.24 ± 0.057; 12.17± 0.000, 0.26 ± 0.000, 55.27 ± 0.000; 16.17 ±0.028, 0.87 ± 0.000, 77.17 ± 0.028 and 10.37 ± 0.000, 0.43 ± 0.028, 52.16 ± 0.000, respectively. Ni is used in electroplating of metal wares. The presence of Ni in the soil samples is not unconnected to household metal wares such as electronics wastes, rechargeable batteries, power tools, condemned CD plates, knives, axes and other farm implements containing nickel used and dumped on the land. Ni is essential in small doses, but it can be dangerous when the maximum tolerable amounts are exceeded (Ni is carcinogenic). Ni released into the environment will largely adsorb to sediment or soil particles and become immobile as a result. However, Ni becomes more mobile and often leaches down to the adjacent groundwater in soils with lower pH values (acidic). As is used as an additive in bronze, wood preservatives, pesticides, and in a variety of semiconductors. Materials containing these items which may have been disposed in the landfill may have added to the concentration of As in the soils around the landfill. Arsenic is not an essential element and generally toxic to plants. As mobility in soil increases as pH increases. Roots are usually the first tissue to be exposed to As, where the metalloid inhibits root extension and proliferation. Upon translocation to the shoot, it can severely inhibit plant growth by slowing or arresting expansion and biomass accumulation as well as compromising plant reproductive capacity through losses in fertility, yield, and fruit production. Cr is used in electroplating processes of metals. Scraped metal disposed in the landfill may have added to the value of Cr in the soil samples. Cr^{6+}, which is the form analysed in the study, is the more toxic form of Cr and it is also more mobile than Cr^{3+}. At the pH (>5) range of the soil samples, Cr^{6+} will be predominant. Soluble and un-adsorbed chromium complexes can leach from soil into groundwater and this leachability of Cr^{6+} increases as soil pH increases.

In all sampling areas, the heavy metal concentrations followed the trend Pb>Cr>Ni>Cd>As. This trend is similar to those reported by other researchers [37,48,49] in similar study.

3.2.2 Human health risks assessment

The hazards quotients (HQ) and cancer risks (CR) of the selected PTMs for adults and children through ingestion, inhalation and dermal exposure pathways at the four sampling areas around the landfill are presented in Tables 4 to 7. Table 4 shows the contaminants' hazards quotient for adult (HQ_{adult}) and children ($HQ_{children}$) and cancer risks for adults (CR_{adult}) and children ($CR_{children}$) around the northern domain of the landfill. The table indicated that of the five contaminants (Cd, Pb, Ni, As and Cr) assessed, Pb pose the highest non-carcinogenic effect to children through ingestion pathway with a value of 9.24×10^{-1}, and the others follow in the order Pb>Cr>Cd>As>Ni. Same order was noticed in the case of adult non-carcinogenic effect due to ingestion with Pb having a value of 9.90×10^{-2} and Ni having the least value of 9.81×10^{-4}. However, the values were below 1.0, hence no adverse effect is expected due to ingestion at the northern domain. For CR due to ingestion pathway, Cr has the highest value for children (4.37×10^{-4}) and adult (4.68×10^{-5}), and Cd has the least values for children (1.33×10^{-5}) and adult (1.42×10^{-6}) with a trend Cr>Ni>Pb>As>Cd. Ingestion cancer risks for children due to exposure to Cr and Ni in the northern domain exceeded the acceptable range (10^{-6} to 10^{-4}), but ingestion CR for adult due to exposure to the five contaminants are within the acceptable range. Inhalation non-carcinogenic risk (HQ) for children and adult due to exposure to the five contaminants are within acceptable limits (<1.0), with Pb having the highest values ($HQ_{children}$ 6.37×10^{-4} and HQ_{adult} 3.64×10^{-4}) and As the least values ($HQ_{children}$ 9.10×10^{-10} and HQ_{adult} 5.17×10^{-10}), in both cases the trend is Pb>Cd>Ni>Cr>As. Inhalation cancer risk due to exposure to the selected contaminants are also within the acceptable range, with Cr having the highest values ($CR_{children}$ 2.89×10^{-10} and CR_{adult} 1.65×10^{-10}), and Pb the least values ($CR_{children}$ 1.07×10^{-12} and CR_{adult} 6.11×10^{-13}), in the two cases the trend follows Cr>Cd>Ni>As>Pb. While dermal non-carcinogenic risk for children and adult was highest with Pb (1.23×10^{-3} and 4.62×10^{-5} respectively) and least with As (3.28×10^{-8}

and 1.29 x 10^{-9} respectively), and dermal cancer risk for children and adult was highest with Cr (8.74 x 10^{-5} and 3.28 x 10^{-6} respectively) and least with Pb for children (5.50 x 10^{-6}) and Cd for adult (9.97 x 10^{-8}). However, all the values were within acceptable limits for both HQ and CR.

Table 5 presents the ingestion, inhalation and dermal HQ and CR of contaminants in soil sample from the southern domain of the landfill for children and adult. The values obtained for the three entry routes showed that HQ for children and adult are within acceptable limits (<1.0). Ingestion $HQ_{children}$ and HQ_{adult} due to Pb were the highest (5.83 x 10^{-1} and 6.25 x 10^{-2} respectively) and that due to Ni were the lowest (5.87 x 10^{-3} and 6.29 x 10^{-4} respectively). Inhalation $HQ_{children}$ and HQ_{adult} due Pb were the highest (4.02 x 10^{-4} and 2.30 x 10^{-4} respectively) and that due to As were the lowest (4.48 x 10^{-10} and 2.56 x 10^{-10} respectively). Same trend were noticed for dermal HQ. Ni pose the highest ingestion CR to children and adult at 2.00 x 10^{-4} and 2.14 x 10^{-5} respectively and Cd pose the lowest ingestion CR to children and adult at 4.30 x 10^{-6} and 4.61 x 10^{-7} respectively. Ingestion $CR_{children}$ values for Ni (2.00 x 10^{-4}) and Cr (2.94 x 10^{-4}) were above the acceptable limit (10^{-6} to 10^{-4}). Cr showed the highest inhalation CR to children and adult at 1.95 x 10^{-10} and 1.12 x 10^{-10} respectively, while Cd showed the lowest inhalation CR to children and adult at 5.62 x 10^{-13} and 3.21 x 10^{-13} respectively. Inhalation CR values obtained for all the selected metals to children and adult were within acceptable limits. Same trend were obtained with dermal CR for children and adult.

Tables 6 and 7 showed values obtained for HQ and CR to children and adult of selected contaminants in soil around the eastern and western domains of Onne landfill. The tables indicated that non carcinogenic risk to children and adult through ingestion, inhalation and skin contact were within acceptable limits. The results also showed that carcinogenic risk due to inhalation and skin contact to both children and adult were within acceptable limit. However, ingestion carcinogenic risk to children due to Ni (2.34 x 10^{-4}) and Cr (3.13 x 10^{-4}) in the eastern domain and Ni (2.75 x 10^{-4}) and Cr (3.69 x 10^{-4}) in the western domain were higher than the acceptable limit, but ingestion CR_{adult} were within acceptable values.

Table 8 presents the hazard index (HI) and total cancer risks (TCR) of the contaminants in soil samples from the four domains around the landfill. It indicated that non carcinogenic risk to children and adult in the four domains were within acceptable values. The values also indicated that total carcinogenic risk to adult TCR_{adult} were within acceptable limit. However, total carcinogenic risk to children $TCR_{children}$ due to Ni and Cr in the northern side, southern side, eastern side and western side (3.74 x 10^{-4} and 5.24 x 10^{-4}, 2.40 x 10^{-4} and 3.54 x 10^{-4}, 2.81 x 10^{-4} and 3.76 x 10^{-4}, and 3.30 x 10^{-4} and 4.43 x 10^{-4} respectively) were above acceptable limit.

Table 7. Hazard quotients and cancer risks of contaminants in soil sample from the Western side of the Onne landfill

Entry route	**Contaminant**	$HQ_{Children}$	HQ_{Adult}	$CR_{Children}$	CR_{Adult}
Ingestion	Cd	1.45 x 10^{-2}	1.55 x 10^{-3}	5.51 x 10^{-6}	5.90 x 10^{-7}
	Pb	4.99 x 10^{-1}	5.34 x 10^{-2}	1.48 x 10^{-5}	1.59 x 10^{-6}
	Ni	8.09 x 10^{-3}	8.67 x 10^{-4}	2.75 x 10^{-4}	2.95 x 10^{-5}
	As	1.06 x 10^{-2}	1.11 x 10^{-3}	4.76 x 10^{-6}	5.10 x 10^{-7}
	Cr	1.85 x 10^{-1}	1.98 x 10^{-2}	3.69 x 10^{-4}	3.96 x 10^{-5}
Inhalation	Cd	4.00 x 10^{-5}	2.28 x 10^{-5}	7.19 x 10^{-13}	4.11 x 10^{-13}
	Pb	3.44 x 10^{-4}	1.96 x 10^{-4}	5.78 x 10^{-13}	3.30 x 10^{-13}
	Ni	4.96 x 10^{-5}	2.83 x 10^{-5}	1.16 x 10^{-12}	6.63 x 10^{-13}
	As	2.91 x 10^{-10}	1.67 x 10^{-10}	3.76 x 10^{-13}	2.15 x 10^{-13}
	Cr	5.09 x 10^{-7}	2.91 x 10^{-7}	2.44 x 10^{-10}	1.40 x 10^{-10}
Dermal	Cd	5.80 x 10^{-6}	2.17 x 10^{-7}	1.10 x 10^{-6}	4.13 x 10^{-8}
	Pb	6.65 x 10^{-4}	2.49 x 10^{-5}	2.97 x 10^{-6}	1.11 x 10^{-7}
	Ni	5.99 x 10^{-6}	2.25 x 10^{-7}	5.50 x 10^{-5}	2.06 x 10^{-6}
	As	1.06 x 10^{-8}	3.96 x 10^{-10}	9.51 x 10^{-7}	3.57 x 10^{-8}
	Cr	6.16 x 10^{-6}	2.31 x 10^{-7}	7.39 x 10^{-5}	2.77 x 10^{-6}

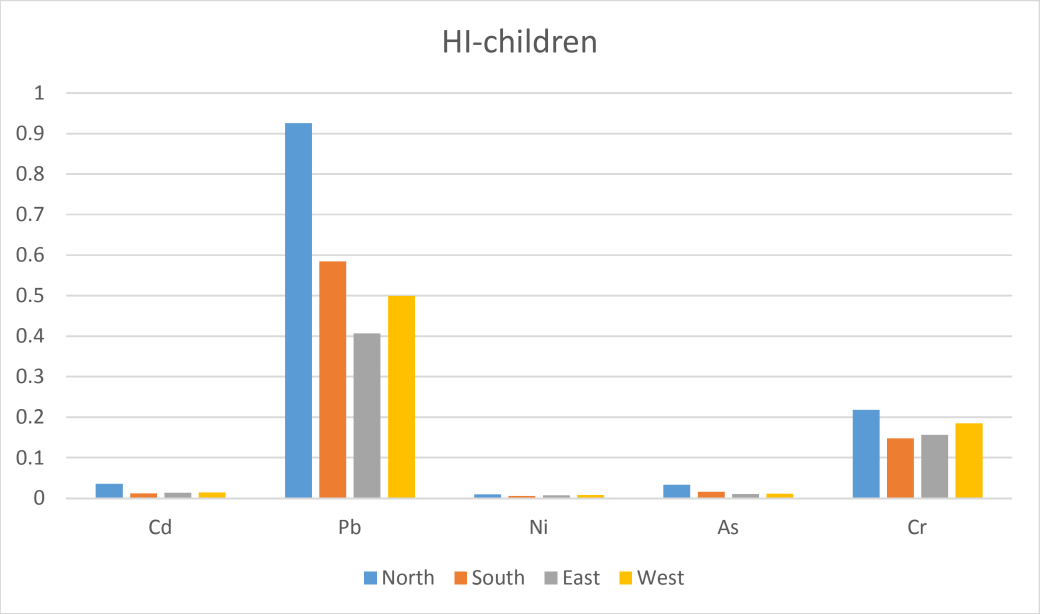

Fig. 3. Cluster column showing hazards index for children due to exposure to the contaminants in the sampling domains

Table 8. Hazard index (HI) and total cancer Risks (TCR) of Contaminants in Soil samples from Onne landfill

Entry route	Contaminant	$HI_{Children}$	HI_{Adult}	$TCR_{Children}$	TCR_{Adult}
Norther side	Cd	3.51×10^{-2}	3.80×10^{-3}	1.60×10^{-5}	1.52×10^{-6}
	Pb	9.25×10^{-1}	9.94×10^{-2}	3.30×10^{-5}	3.15×10^{-6}
	Ni	9.22×10^{-3}	1.01×10^{-3}	3.74×10^{-4}	3.57×10^{-5}
	As	3.28×10^{-2}	3.51×10^{-3}	1.77×10^{-5}	1.69×10^{-6}
	Cr	2.18×10^{-1}	2.34×10^{-2}	5.24×10^{-4}	5.01×10^{-5}
Southern side	Cd	1.14×10^{-2}	1.23×10^{-3}	5.16×10^{-6}	4.93×10^{-7}
	Pb	5.84×10^{-1}	6.27×10^{-2}	2.08×10^{-5}	1.99×10^{-6}
	Ni	5.91×10^{-3}	6.50×10^{-4}	2.40×10^{-4}	2.29×10^{-5}
	As	1.62×10^{-2}	1.74×10^{-3}	8.76×10^{-6}	8.37×10^{-7}
	Cr	1.48×10^{-1}	1.58×10^{-2}	3.54×10^{-4}	3.39×10^{-5}
Eastern side	Cd	1.41×10^{-2}	1.53×10^{-3}	6.40×10^{-6}	6.12×10^{-7}
	Pb	4.06×10^{-1}	4.36×10^{-2}	1.45×10^{-5}	1.38×10^{-6}
	Ni	6.94×10^{-3}	7.63×10^{-4}	2.81×10^{-4}	2.69×10^{-5}
	As	9.81×10^{-3}	1.05×10^{-3}	5.30×10^{-6}	5.06×10^{-7}
	Cr	1.56×10^{-1}	1.68×10^{-2}	3.76×10^{-4}	3.59×10^{-5}
Western side	Cd	1.45×10^{-2}	1.57×10^{-3}	6.61×10^{-6}	6.31×10^{-7}
	Pb	5.00×10^{-1}	5.37×10^{-2}	1.78×10^{-5}	1.70×10^{-6}
	Ni	8.15×10^{-3}	8.95×10^{-4}	3.30×10^{-4}	3.15×10^{-5}
	As	1.06×10^{-2}	1.13×10^{-3}	5.71×10^{-6}	5.45×10^{-7}
	Cr	1.85×10^{-1}	1.98×10^{-2}	4.43×10^{-4}	4.23×10^{-5}

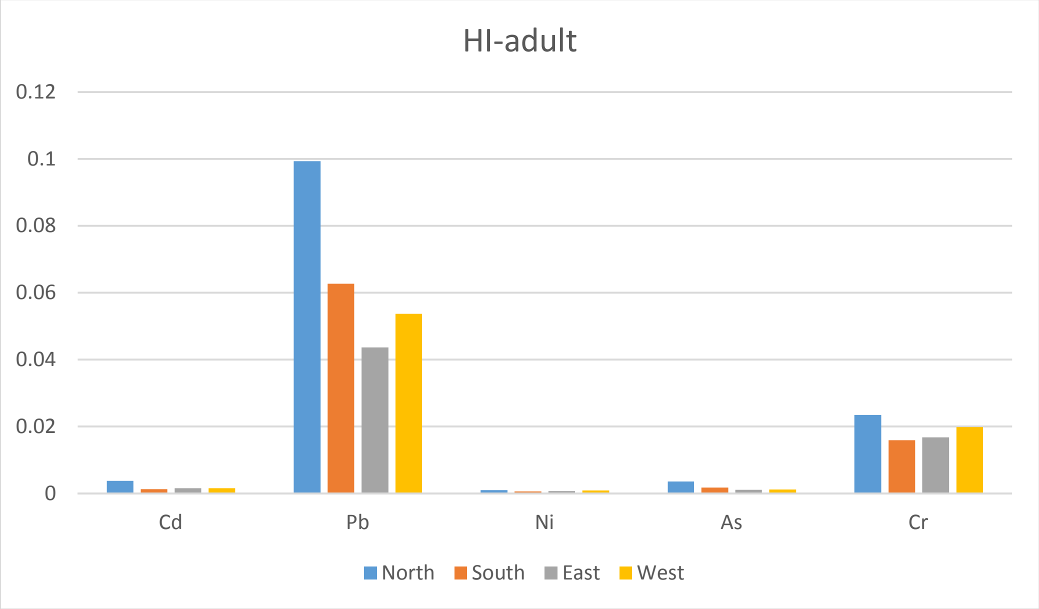

Fig. 4. Cluster column showing hazards index for adult due to exposure to the contaminants in the sampling domains

Figs 3 and 4 present cluster columns of hazard index (HI) for children and adult exposure to the contaminants in the four sampling domains respectively. The columns indicated that HI due to children and adults' exposure to Pb were highest in the northern domain followed by the southern domain, western domain and eastern domain in the order north>south>west>east. HI due to children and adults' exposure to Cr is in the order north>west>east>south. Values for children were higher than those of adults. Though the values were less than 1.0, there is concern as it is approaching 1.0 and therefore, steps need to be taken to control the waste dumping activities in the northern side of the landfill to enable remediation actions to be activated. Figs 5 and 6 present cluster columns of total cancer risk (TCR) for children and adult exposure to the selected contaminants in the four sampling domains respectively. The columns revealed that TCR due to children and adults' exposure to Ni and Cr were highest in the northern domain following the sequence north>west>east>south with both contaminants. The values for children were again higher than those of adults and both Ni and Cr respectively.

In general, the hazards associated with children exposure to the selected contaminants through ingestion, inhalation and skin contact were higher than those of the adults. It does revealed that children are more susceptible to potentially toxic metal contaminations than adults. Children are more vulnerable to a known dose of contaminants because they are more likely to inadvertently ingest substantial quantities of contaminants due to their hand-to-mouth behavior, ingestion is therefore a key contaminants exposure pathway for children. This finding compares favourably with the inference drawn by [50] in their work on a municipal waste landfill in Uyo. In a similar manner, [51] worked on human health risks assessment of iron mines in Itakpe and Agbaja in Kogi state and observed that $HI_{children}$ was greater than HI_{adults}. [52] also showed that $HI_{children}$ was higher than that HI_{adults} when they conducted a health risk assessment of heavy metals in soils from partial areas of Daye city in China. Residential houses and business shops are gradually being developed close to the landfill in Onne. It is a general norm that women who own shops carry their children to the shop and in the process the children are exposed to the contaminants by mouthing non-food items from the ground. In the same manner, children in residential areas who are allowed to play outdoor also mouth non-food materials and are therefore expose to the hazards. It is therefore advisable to prevent children exposure at the landfill. Scavengers and operators of the landfill are likely to stay within the landfill beyond tolerable timeframe and are therefore particularly exposed to these contaminants. Adults should therefore

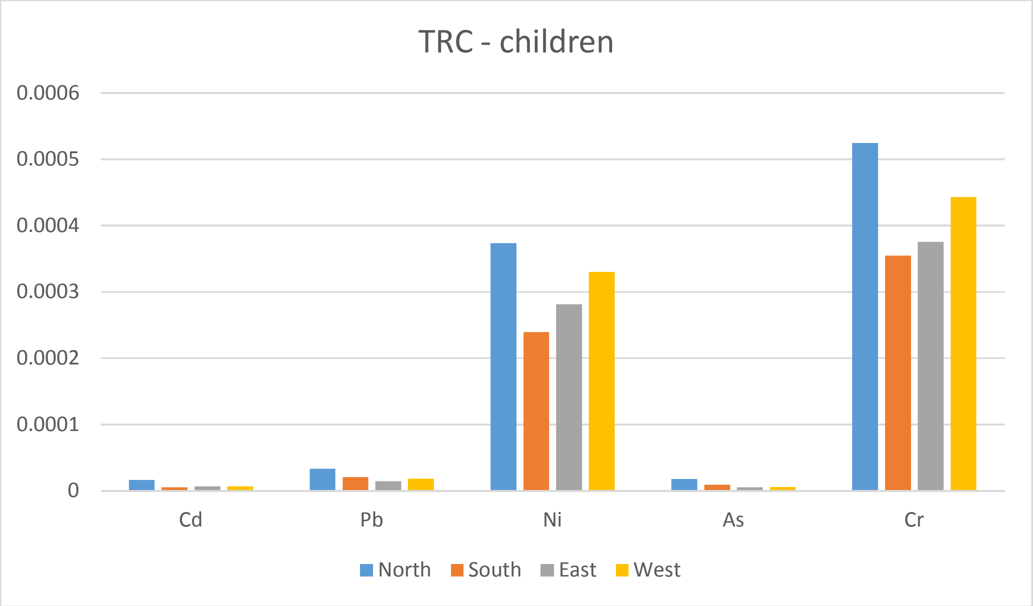

Fig. 5. Cluster column showing total cancer risks for children due to exposure to the contaminants in the sampling domains

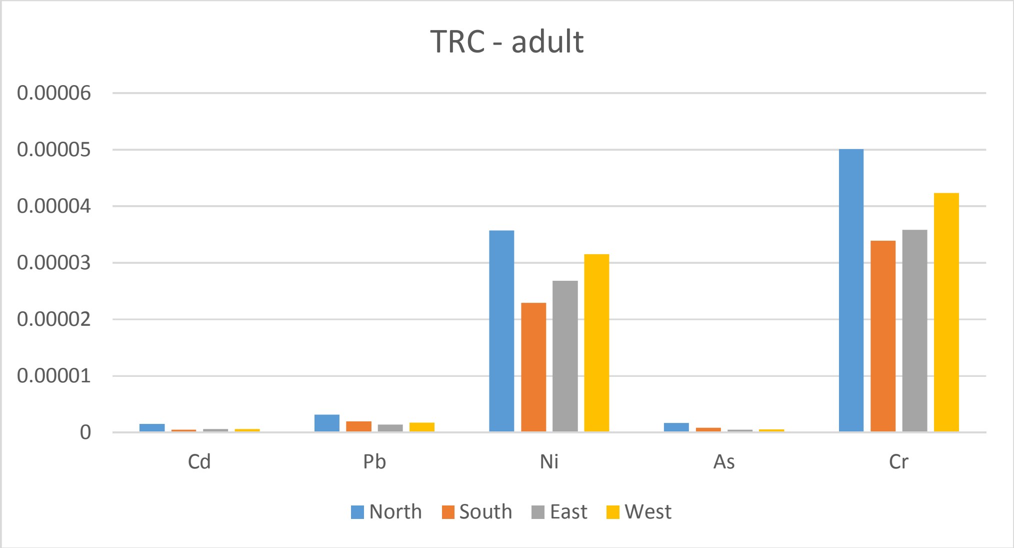

Fig. 6. Cluster column showing total cancer risks for adult due to exposure to the contaminants in the sampling domains

limit man-hour in their activities at the landfill. Furthermore, Pawpaw (*Carica papaya*), vegetables and plantain (*Musa paradisiaca L.*) were sighted within the sampling areas, studies [53,54] have shown that these plants take up heavy metals from the soil, it is therefore recommended that further research be carried out on the concentration of these metals in those edible plants so as to advice the public on the health hazards associated with their consumption.

4. CONCLUSION

This study showed that among the selected potentially toxic metals Pb has the highest concentration followed by Cr, Ni, Cd and As in that order. Human health risk assessment revealed that ingestion pathway is the greatest contributor to non-carcinogenic and carcinogenic risks followed by skin contact and the least was inhalation. The results also showed that children are more susceptible to both non-carcinogenic and cancer risks probably due to mouthing of non-food items. The HI values were less than 1 for both adult and children, which indicates that the hazards are considered low at all the four domains of the landfill. The total cancer risks TCR for adults due to exposure to the five contaminants in the four domains was also low, but the TCR for children due to exposure to Ni and Cr at the four domains were higher than the limit. It is recommended that measures be put in place that would adequately control the source of contaminants into the landfill, especially as residential houses are being developed close to the landfill. Waste management best practices such as waste to wealth could also help. Alternatively, the government could relocate the landfill to a properly designed facility.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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