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Assessment of Levels and Ecological Risks of Some Selected Potentially Toxic Metals in Soils around Onne Dumpsite, Rivers State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author PA designed the study, managed the literature searches, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors GIO and BSC managed the analyses of the study. Author BSC performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

The concentrations of selected potentially toxic metals and other soil physico-chemical variables in soil receptacles of a solid waste dumpsite at Onne, Nigeria were assessed to ascertain the levels of contamination and ecological risks. Surface soils (0 – 20 cm depth) from four sampling areas (north, south, east and west) of the dumpsite were analyzed for Cd, Pb, Ni, As and Cr, using atomic absorption spectroscopy. Single and integrated ecological risks indices were calculated using established models. Results revealed the mean values (mg/kg) of Cd (1.00 – 3.09), Pb (125.37 – 285.48), Ni (10.37 – 16.17), As (0.26 – 0.87), Cr (52.16 – 77.17). Assessment of ecological risk indices for north, south, east and west showed {PLI (2.38, 1.27, 1.17 and 1.33), EF (1.01, 16.0, 13.90 and 56.0), C_d (21.50, 11.10, 9.49 and 10.90), PERI (392.0, 132.0, 148.0 and 157.0), PI_{Avg} (5.17, 2.55, 2.27 and 2.56), $PI_{Nemerow}$ (7.75, 3.80, 3.18 and 3.38) } respectively. These implied that the soils around the dumpsite area were polluted due to enrichment of the selected metals and therefore of low quality. Ecological risk reduction strategies were also recommended.

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Keywords: Dumpsite; soil; heavy metals; ecological risks; contamination.

1. INTRODUCTION

Soil is a very important component of terrestrial ecosystem. It is essential to human because, it is the top layer of the earth in which humans grow plants. This makes it play a vital role in food chain. Several people who leave around dumpsites have engaged in the habit of planting crops on dumpsites of soil because of it assumed fertility [1]. In several instances, the soil is contaminated with heavy metals resulting from the wastes dumped on the soil. Heavy metal pollution is a serious global environmental problem as it contributes to ecological disturbances [2].

Heavy metals are released into the environment by both natural and anthropogenic sources. The main natural sources of metals in soils are chemical weathering of mineral; the anthropogenic sources are associated mainly with industrial, agricultural, mining, land disposal of waste, waste incineration, and mechanic workshops. Heavy metals contamination of topsoil has been a major concern with respect to their toxicity, persistence and non-degradability in the environment [3]. Toxicity of these compounds has been reported extensively [3, 4, 5]. They accumulate overtime in soils, which act as a sink from which these toxicants are released to the groundwater and plants and end up through the food chain thereby causing various toxicological effects. Effects of elevated concentrations of heavy metals to soil functions, soil microbial composition and microbial growth have long been reported. Human activities in urban areas largely contribute to the contamination of urban soils and this is a major health concern [3]

Dumpsite is a designated place where materials considered to be wastes are disposed. It is the oldest method of waste treatment. Historically, dumpsites have been the most common method of unorganized waste disposal and remain so in many places around the world, especially developing countries including Nigeria [6]. Most dumpsites are located within the vicinity of living communities and wetland [7].

Dumpsites as currently practiced in most parts of Nigeria is just an open land identified and designated as a site where individuals and organizations can dispose any substance(s) which is/are considered not fit for their intended use. The site is neither lined nor base-prepared to selectively adsorb potentially toxic substances. This makes the site likely to release contaminants to the surrounding environmental media. Landfills are one of the sources of groundwater and soil pollution due to the production of Leachate and transportation of the contamination to farther points in the ecosystem [8]. The contaminations of soil, water and air with heavy metals even at low concentrations are known to have potential impact on environment and human health [9]. Furthermore, landfills are a major contributor to the world's anthropogenic greenhouse gas (GHG) emissions because large amount of CH_4 and CO_2 are generated from the degradation process of deposited waste in landfills [10].

Onne is a community housing the Oil and Gas Free Zone in Rivers state Nigeria. Over 120 firms are located within and around the free zone and over 50% of the firms and the entire community dispose their solid wastes at the dumpsite in Onne. This practice has been in place for over 15 years without adequate regulation. The population of Onne has also grown with the development of the free zone and the dumpsite is almost at the center of the town currently. Increasing population and proliferation of industrial activities lead to increasing waste volume and hence concentration of heavy metals in soils which ultimately lead to growing environmental pollution posing threat to the environment [11,12,13,14].

Most of the times, the wastes at the dumpsite in Onne are burnt. When metal containing wastes are burnt, ashes with high metallic contents are produced which would possibly dissolve in rain water, leached into the soil and transferred into the food chain via absorption by plants [11].

This study evaluates the ecological impacts of the dumpsite in Onne using some ecological risk indices for some selected heavy metals in soils around the dumpsite.

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 dumpsite and composited in a labelled sealed polyethylene package (samples were collected at 30 m North, 30 m South, 30 m east and 30 m West away from the dumpsite) 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.

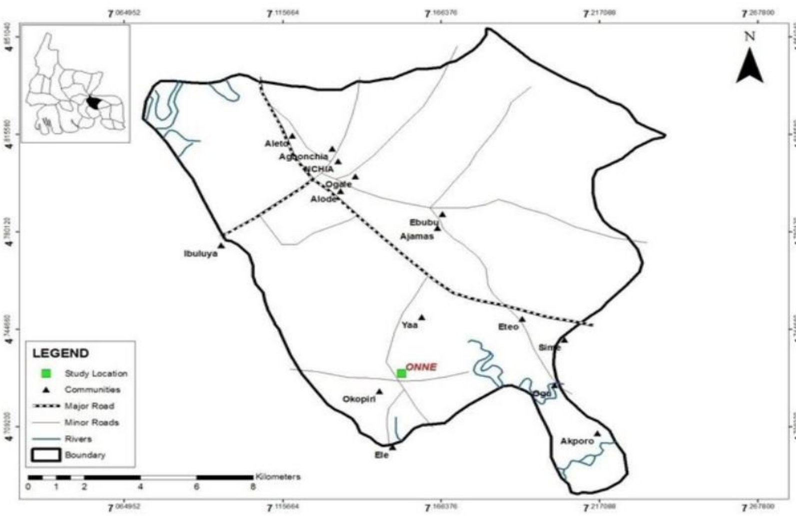

Fig. 1. Map of rivers state indication the study area –Onne

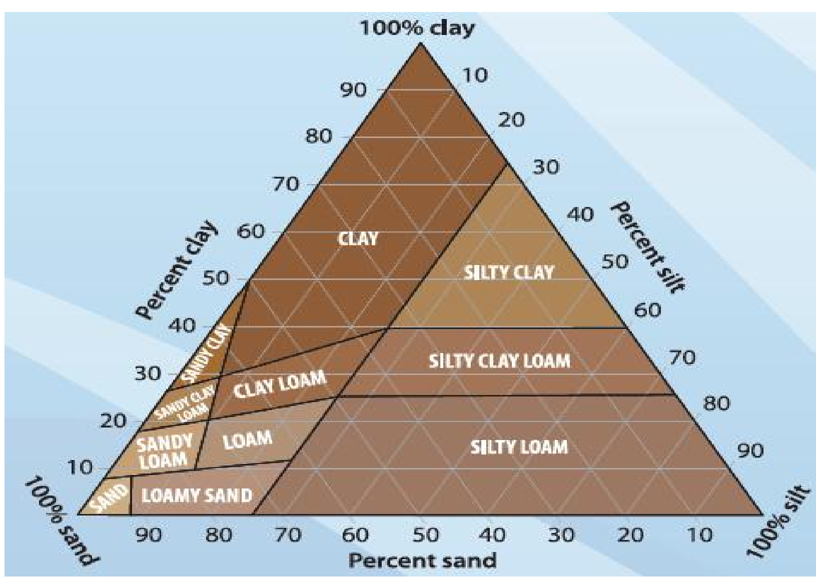

Fig. 2. Triangle of soil texture used to classify soil samples

2.3 Ecological Risk Indices

Ecological indices such as metal pollution index, potential ecological risk index (PERI), contamination factor, pollution load index, enrichment factor, geoaccumulation index, degree of contamination, average pollution and Nemerow pollution indices were determined using the models described by [15].

The metal pollution index is expressed as:

$$\text{MPI} = \frac{\text{Concentration of metal in soil}}{\text{reference soil (control)}} \tag{1}$$

The values of metal pollution index of soil greater than 1 (> 1), and those less than (< 1) define the pollution range (< 0.1 as very slight contamination, 0.10 – 0.25 as slight contamination, 0.26 – 0.5 as moderate contamination, 0.51 – 0.75 as severe contamination, 0.76 – 1.00 as very severe contamination, 1.1 – 2.0 as slight pollution, 2.1 – 4.0 as moderate pollution, 4.1 – 8.0 as severe pollution, 8.1 – 16.0 as very severe pollution and > 16.0 as excessive pollution).

The contamination factor expressed as:

$$CF = \frac{C_{metal}}{C_{backgrou}} \tag{2}$$

where C_{metal} is the concentration of a single metal in the soil and $C_{background}$ is the metal concentration in pre-industrial reference level for the metal

Pollution load index PLI is a potent tool in PTM pollution evaluation for each site and was evaluated using:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots CF_n)^{1/n} \tag{3}$$

where: n = number of metals and CF = contamination factor. The PLI value higher than 1 indicates the samples have been polluted while the PLI value less than 1 indicates no pollution occurred.

Enrichment factor (EF) was determined using:

$$EF = \frac{(C_i/C_{ie})_S}{(C_i/C_{ie})_{RS}} \tag{4}$$

Where *Ci* is the content of element *i* in the sample of interest or the selected reference sample, and *Cie* is content of immobile element in the sample or the selected reference sample.

Index of geo-accumulation was calculated by the following expression:

$$I_{geo} = \log_2 \frac{C_i}{1.5C_{ri}} \tag{5}$$

Where *Ci* is the measured concentration of the examined metal *i* in the soil, and *Cri* is the geochemical background concentration or reference value of the metal *i*.

The degree of contamination (*C*d) was determined using:

$$C_d = \sum_{i=1}^{m} C_f^i \tag{6}$$

Where C_f^i is the single index of contamination factor, and *m* is the number of the heavy metal species. Risk is low when Cd < m, moderate when m $\leq$ Cd < 2m, considerable when m $\leq C_d$ < 4m and very high when C_d > 4m.

Potential ecological risk index (PERI) is used to evaluate the harm of heavy metals in a soil sample. PERI could be calculated by using the following formula:

$$\text{RI} = \sum E_f^i \tag{7}$$

where RI is the potential; E_f^i is the potential ecological risk index for single heavy metal pollution and can be calculated as:

$$E_f^i = C_f^i \times T_f^i \tag{8}$$

T_f^i is the response coefficient for the toxicity of the single metal. C_f^i is the pollution index and can be defined as:

$$C_f^i = \frac{C_s^i}{C_n^i} \tag{9}$$

Where C_s^i is the concentration of heavy metal in the soil and C_n^i is the reference value which is the concentration of heavy metal in a controlled sample.

Potential ecological risk is low when PERI < 150, moderate when 150 $\leq$ PERI< 300, considerable when 300 $\leq$ PERI < 600 and very high when PERI > 600.

An average of pollution index (PI_{Avg}) was defined as

$$PI_{Avg} = \frac{1}{m}\sum_{i=1}^{m} P_i \tag{10}$$

Where P_i is the single pollution index of heavy metal i, and m is the number of the heavy metal species.

A PI_{Avg} value >1.0 indicates low quality soil due to contamination.

A Nemerow pollution index ($PI_{Nemerow}$) was applied to assess the quality of soil environment widely and was defined as:

$$PI_{Nemerow} = \sqrt{\frac{(\frac{1}{m}\sum_{i=1}^{m} P_i)^2 + P_{i\max}^{\;2}}{2}} \tag{11}$$

Where P_i is the single pollution index of heavy metal i; Pi_{max} is the maximum value of the single pollution indices of all heavy metals, and m is the number of the heavy metal species. The soil environment is a considered a safety domain when $PI_{Nemerow}$ < 0.7, precaution domain when 0.7 $\leq PI_{Nemerow}$ < 0.1, slightly polluted domain when 1.0 $\leq PI_{Nemerow}$ < 2.0, moderately polluted domain when 2.0 $\leq PI_{Nemerow}$ < 3.0 and seriously polluted domain when $PI_{Nemerow}$ > 3.0

3. RESULTS AND DISCUSSION

3.1 Results

Physico-chemical attributes of the soil samples from the dumpsite in Onne are presented in Table 1. The analysis of the soil texture using the textural triangle of soil (Fig. 2) for the soil samples are indicated in Table 1. Ecological risk indices determined in this study are presented in Tables 2 and 3. Single indices as 2 factor interactions are presented in Figs3a – 3e.

3.2 Discussion

3.2.1 Physicochemical attributes

The results showed pH range from 5.58 ± 0.000 to 6.20 ± 0.141. The highest pH was obtained in the sample taken from Northern side of the dumpsite while the lowest obtained in the sample taken from southern side of the dumpsite. The pH range implies that the soil around the dumpsite is mildly acidic. This result is relatively lower than the pH value (7.20 ± 0.10) reported by [15], but compared favourably with the mean pH value (6.4) reported by [16] 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.

Conductivity is another important soil characteristics as it indicates the presence of harmful salts in the soil resulting from low rainfall and high evaporation. 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 [15], but higher than the value (142.00 μScm^{-1}) reported by [17] in similar studies.

Soil organic matter (SOM) is an important constituent of the soil resource base, which 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, which differ with climate, soil type and farming system [18]. Organic matter (%) in the soil samples 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% [19], hence the values of the SOM in the samples compare favourably.

Table 1. Physico-chemical attributes of soil sample from Onne dumpsite

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		Texture Class		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 2. Single element pollution indices

Pollution indices and Region	Cd (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	As (mg/kg)	Cr (mg/kg)
MPI NORTH	9.66^{a}±0.014	7.48^{b}±0.000	2.07^{a}±0.000	5.12^{a}±0.014	1.54^{a}±0.014
MPI SOUTH	3.13^{f}±0.000	4.73^{e}±0.014	1.33^{d}±0.014	2.53^{b}±0.000	1.04^{d}±0.014
MPI EAST	3.88^{d}±0.014	3.29^{h}±0.000	1.56^{c}±0.014	1.53^{e}±0.014	1.10^{b}±0.000
MPI WEST	4.00^{c}±0.000	4.04^{g}±0.000	1.83^{b}±0.014	1.65^{d}±0.000	1.30^{c}±0.014
CF NORTH	7.73^{b}±0.000	10.54^{a}±0.049	0.56^{e}±0.000	1.30^{f}±0.000	1.30^{b}±0.000
CF SOUTH	2.50^{b}±0.000	6.68^{d}±0.014	0.36^{h}±0.000	0.64^{h}±0.000	0.88^{f}±0.014
CF EAST	3.10^{f}±0.000	4.64^{c}±0.000	0.42^{g}±0.014	0.3^{9i}±0.000	0.93^{e}±0.014
CF WEST	3.20^{e}±0.000	5.71^{f}±0.014	0.49^{f}±0.000	0.42^{i}±0.014	1.10^{c}±0.000
Igeo NORTH	2.68^{g}±0.000	2.32^{i}±0.014	0.46^{f}±0.000	1.77^{c}±0.000	0.03^{g}±0.000
Igeo SOUTH	1.06^{k}±0.014	1.66^{j}±0.014	-0.18^{k}±0.000	0.75^{g}±0.000	-0.53^{j}±0.000
Igeo EAST	1.37^{j}±0.014	1.13^{l}±0.000	0.05^{j}±0.000	0.03^{k}±0.014	-0.45^{i}±0.014
Igeo WEST	1.42^{i}±0.014	1.43^{k}±0.000	0.29^{i}±0.014	0.13^{j}±0.000	-0.21^{h}±0.014

Values are mean ± SD of triplicate samples.
^{abc}Mean value bearing different superscripts in the same column differ significantly (P<0.05)
Key: MPI=metal pollution index, CF= contamination factor, Igeo= index of geo-accumulation
**-ve values are <0.01*

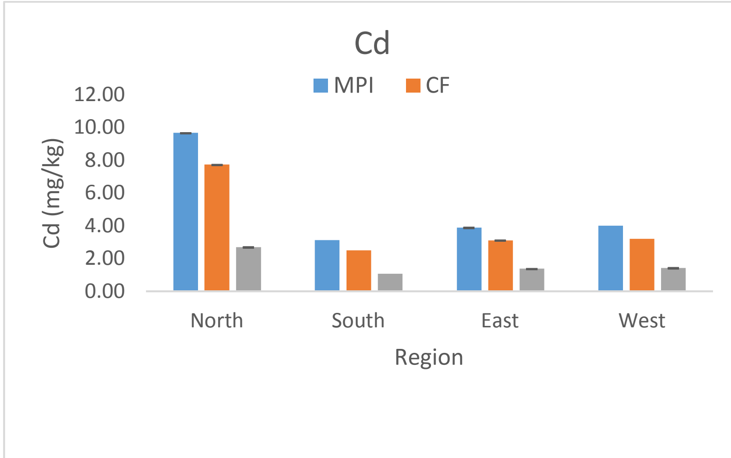

Fig. 3a. Single indices as 2 factor interaction (2FI)

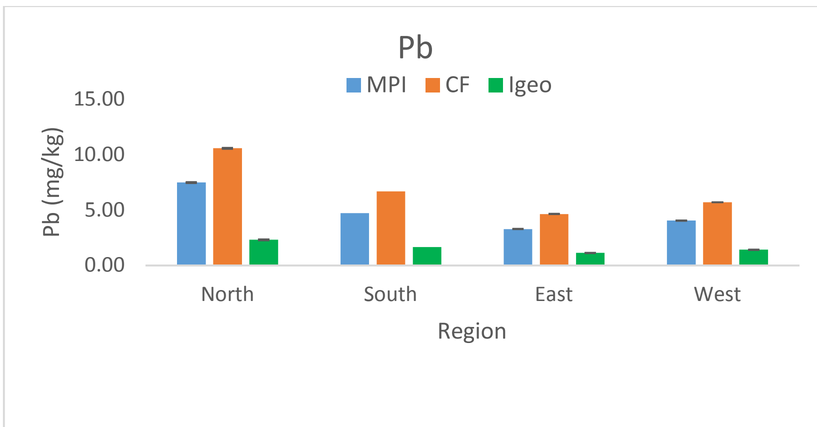

Fig. 3b. Single indices as 2 factor interaction (2FI)

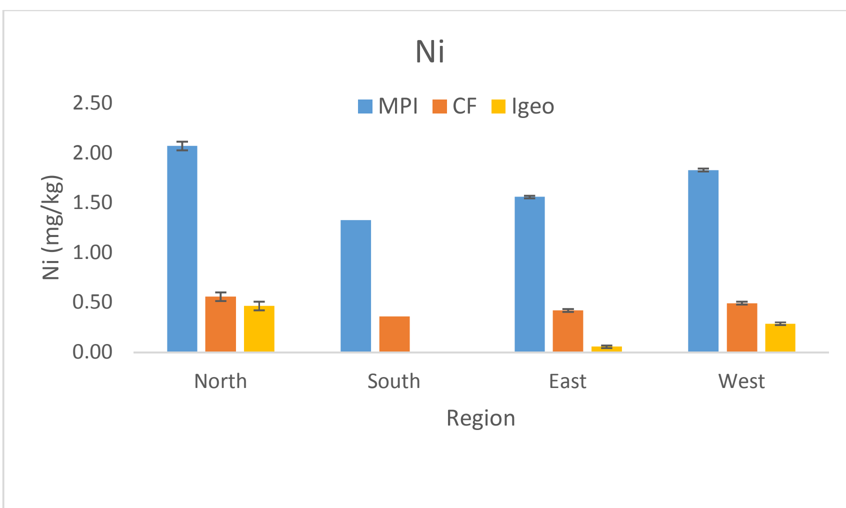

Fig. 3c. Single indices as 2 factor interaction (2FI)

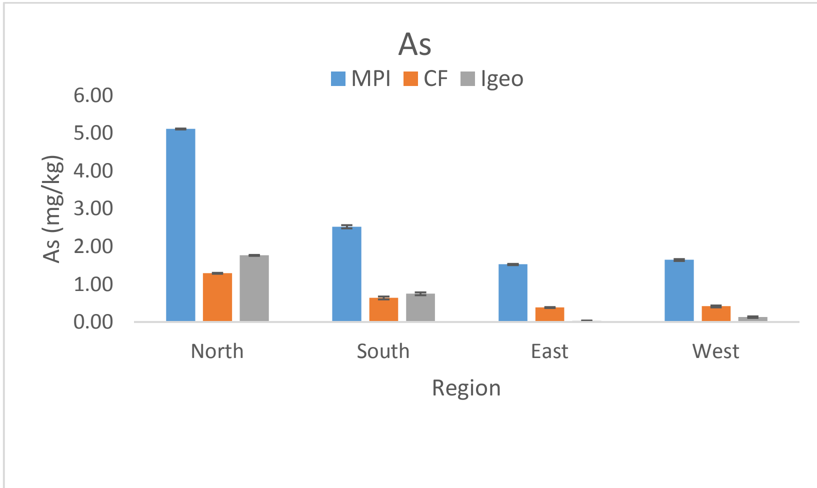

Fig. 3d. Single indices as 2 factor interaction (2FI)

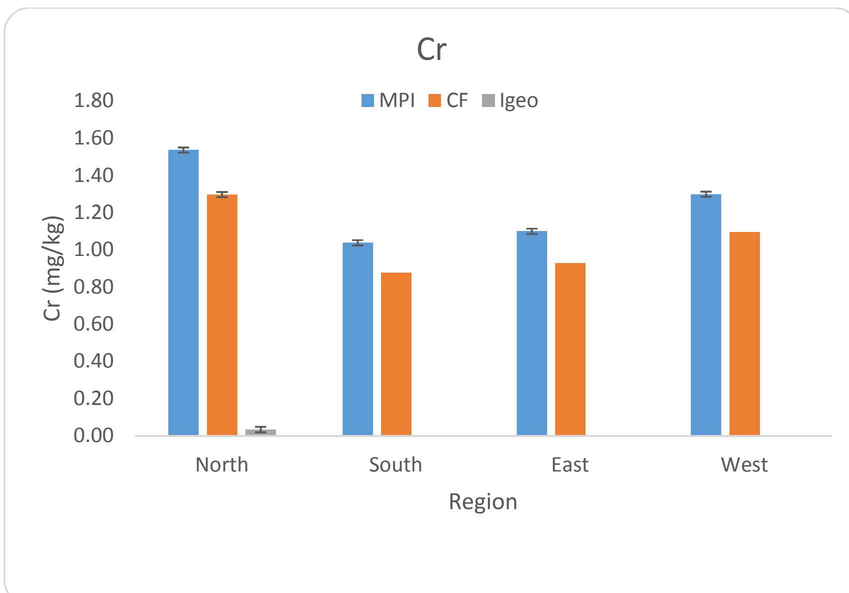

Fig. 3e. Single indices as 2 factor interaction (2FI)

Bulk density is an indicator of the level of soil compaction. 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} [20]. 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.

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 1) showed that the soil sample is loamy sand.

The cation exchange capacity of soil is the maximum amount of cations that 100 g of dry soil can absorb [21]. 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 [22]. 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 PTMs in soil [23]. It has been reported [15] 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 dumpsite were 1.28 ± 0.014, 1.24 ± 0.028, 3.09 ± 0.000 and 1.00 ± 0.000, 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 dumpsite, and may have been responsible for the high level of Cd in the dumpsite. 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 dumpsite and may be responsible for the high level of Pb in the soil around the dumpsite. 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) [24]. Pb is a toxic metal with exceptionally low mobility and high bioavailability. Pb is known to persist in surface soils for a long time [25] 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 dumpsite may have added to the concentration of As in the soils around the dumpsite. 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 dumpsite 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 PTM concentrations followed the trend Pb>Cr>Ni>Cd>As. This trend is similar to those reported by other researchers [6,15,26] in similar study.

3.2.2 Ecological risks assessment

Table 2 shows the single element pollution indices such as metal pollution index (MPI), contamination factor (CF) and index of geo-accumulation (I-geo) for the five metals determined in this study for the site.

3.2.2.1 Metal pollution index

Metal pollution index is used to determine which metal represents the highest threat to the soil environment. The soil environment North to the dumpsite is very severely polluted with Cd, severely polluted with Pb and As, moderately polluted with Ni, and slightly polluted with Cr. The soil environment West to the site is moderately polluted with Cd and Pb, slightly polluted with Ni and Cr, and very slightly contaminated with As. The soil environment South of the dumpsite is severely polluted with Pb, moderately polluted with Cd and As, slightly polluted with Ni and very severely contaminated with Cr. while the soil environment East of the dumpsite showed moderate pollution with Cd and Pb and slight pollution with Ni, As and Cr.

3.2.2.2 Contamination factor

The contamination factor enables assessment of the soil contamination taking into account the potentially toxic metals content from the surface of the soil and their background levels. The soil environment North of the dumpsite showed very high contamination with Cd and Pb, moderate contamination with As and Cr, and low contamination with Ni. South of the dumpsite showed very high contamination with Pb, moderate contamination with Cd and low contamination with Ni, As and Cr. in the west, the soil environment showed considerable contamination with Cd and Pb, moderate contamination with Cr and low contamination with Ni and As. While in the south, the soil environment showed considerable contamination with Cd and Pb, and low contamination with Ni, As and Cr.

3.2.2.3 Index of geo-accumulation

The I-geo is used to assess the presence and intensity of anthropogenic contaminant deposition on surface of the soil. Cd and Pb in the soil environment North of the dumpsite have accumulated to the extent of moderate to strongly polluted situation, As showed moderately polluted situation, while Ni and Cr are increasing from unpolluted to moderately polluted situation. South of the dumpsite, Cd and Pb have moderately polluted the soil environment, As is gradually increasing from unpolluted to moderately polluted situation, while Ni and Cr showed unpolluted status. Towards the east, the soil environment is moderately polluted with Cd and Pb, As and Ni are increasing in intensity from unpolluted to moderately polluted situation, while Cr still showed unpolluted in intensity. Towards the west, Cd and Pb intensity showed moderate pollution, Ni and as are increasing in their intensity from unpolluted to moderate pollution while Cr is still unpolluted in intensity.

In order to have a total assessment of the extent of soil deterioration around the dumpsite, it is necessary to calculate some integrated ecological indices such as pollution load index, enrichment factor, potential ecological risk index, degree of contamination, average of pollution index and nemerow pollution index. Table 3 shows the values of these indices in the soil samples taken from environments towards the north, south, east and west of the dumpsite.

Table 3. Integrated ecological risks indices

Ecological indices	North		South		East		West	
PLI	2.38[a]	± 0.014	1.27[b]	± 0.014	1.17[c]	± 0.000	1.33[b]	± 0.042
EF	1.01[d]	± 0.000	16.05[b]	± 0.014	13.91[c]	± 0.000	55.96[a]	± 0.042
PERI	391.71[a]	± 0.014	131.74[d]	± 0.014	147.51[c]	± 0.000	157.49[b]	± 0.000
Cd	21.43[a]	± 0.035	11.05[b]	± 0.000	9.48[d]	± 0.014	10.92[c]	± 0.014
PI-Avg	5.17[a]	± 0.000	2.55[b]	± 0.000	2.27[c]	± 0.014	2.56[b]	± 0.000
PI-Nemerow	7.75[a]	± 0.014	3.80[b]	± 0.000	3.15[d]	± 0.064	3.38[c]	± 0.000

Values are mean ± SD of triplicate samples.

[abc]*Mean value bearing different superscripts in the same row differ significantly (P<0.05)*

3.2.2.4 Pollution load index

The severity of pollution and its variation across the sampling areas around the dumpsite were determined using the PLI. The PLI is a quick tool to prove the level of deterioration of the soil condition due to accumulation of potentially toxic metals. It is a geometric average of metal pollution index [27]. Table 3 shows that the soil environment north, south, west and east of the dumpsite are polluted due to the presence of Cd, Pb, Ni, As and Cr.

3.2.2.5 Enrichment factor

Enrichment factor is the extent of possible impact of anthropogenic activities on the metal concentration in the soil. The content of potentially toxic metal characterized by low variability of occurrence (LV) is used as a reference to identify the expected impact of anthropogenesis on the PTMs in the soil [28]. Reference elements are elements which are stable in the soil, and are characterized by non-vertical mobility and/or degradation phenomena [29]. The constituent chosen in this study was Mn whose concentration is generally not anthropogenically altered. The EF values in Table 3 speculate that contaminations originating from anthropogenic sources in the soil environment of the dumpsite has increased from depletion level to minimal enrichment in the north, significant enrichment in the south and east, while it has increased to extremely high enrichment in the west.

3.2.2.6 Potential ecological risk index (PERI)

The PERI is one of the accurate ways used to assess the harm of PTMs in the soils. It takes into consideration the different background values of the geographical area and combines environmental chemistry with biological toxicology and ecology [30]. PERI considers the concentration, the toxic level, synergy and ecological sensitivity of the metals [31]. The values of PERI in Table 3 indicate that there is considerable ecological risks in the soil environment north of the dumpsite, moderate ecological risks west of the dumpsite, and low ecological risks south and east of the dumpsite.

3.2.2.7 Degree of contamination

The degree of contamination is the sum of all the contamination factors for a given set of soil pollutant divided by the number of analyzed pollutants [32]. It provides a measure of the degree of overall contamination in surface layers in a particular sampling site. Table 3 shows values in the soil environment north of the dumpsite having very high degree of contamination, the south and west having considerable degree of contamination, while east has moderate degree of contamination.

3.2.2.8 Average pollution index

The average pollution index is used to assess the quality of soil [28] and thus communicate to the public how polluted the environment currently is or how polluted it is forecasted to become. Table 3 shows values of average pollution index (PI_{-avg}) for the four sampling areas of the dumpsite. The values indicated that the northern, southern, eastern and western areas of the dumpsite have low quality soils due to contamination. As these values increases with anthropogenic activities, there would be an increasing large percentage of the population likely to experience increasing severe adverse health effects.

3.2.2.9 Nemerow pollution index

The Nemerow pollution index ($PI_{-Nemerow}$) allows an assessment of the overall degree of pollution of the soil and includes the contents of all analyzed potentially toxic metals. The PI-nemerow calculated for soils in the northern, southern, western and eastern areas of the dumpsite are shown in Table 3. The values indicated that on the wider scope of the soil environment, the four areas of the dumpsite were seriously polluted domain and therefore ecologically unsafe. The values (3.18 – 7.75) in this study were higher than those (1.95) reported by [30] for dumpsite in northeast China.

Figs 3a-3e represent single indices as 2 factor interaction for Cd, Pb, Ni, As and Cr respectively. In Fig. 3a, the trend of single ecological indices due to Cd follows MPI>CF>I_{-geo} in soils in the north, south, east and west of the dumpsite. In Fig. 3b, the trend due to Pb is CF>MPI>I-geo in all four areas of the dumpsite. Fig. 3c showed the trend due to Ni is MPI>CF>I_{-geo} in the four regions of the dumpsite. Fig. 3d showed the trend due to As is somewhat erratic, in the north and south the trend was MPI>I_{-geo}>CF, in the east and west it was MPI>CF>I_{-geo}. Fig. 3e shows the trend due to Cr in the four areas of the dumpsite to be MPI>CF>I_{-geo}.

4. CONCLUSION

The concentrations of the selected potentially toxic metals were high in the soil receptacles surrounding the dumpsite which poses ecological risks to the ecosystem. Industrialization and urbanization of Onne communities contributed to the high levels of the metals in the soil samples. Wastes segregation should be encouraged in the various industries and communities within Onne while awareness on basic concept of waste reduction, reuse, recycle and recovery should be enhanced. Continual monitoring of the soils around the dumpsite area to ensure the population is aware of the ecological risks around the area is recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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