

Heavy Metals and Health Risk Assessment of Topsoil in Primary School Playgrounds in Edo State, Nigeria

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Abstract

The accumulation and contamination of the environment by heavy metals is a serious problem around the world due to its toxicity and persistence. Thus, the concentrations of heavy metals in top soils of selected public primary school playgrounds were determined using standards methods. Results showed that Cadmium (Cd) was below detection limits in all the Stations, while Lead (Pb) was only detected in Station 2 ($0.01 \pm 0.01 \text{ mg/kg}$). Among all the heavy metals analyzed, Iron (Fe) had the highest mean concentration across all the stations with minimum and maximum value of $16.57 \pm 3.39 \text{ mg/kg}$ (Station 1) and $18.87 \pm 1.03 \text{ mg/kg}$ (Station 3) respectively. The values of heavy metal pollution index (Contamination Factors, Contamination Degree, Pollution Load Index, Geoaccumulation Index) were less than one across the three stations which implies that all stations were practically uncontaminated. Assessment of health risks of heavy metals to children indicates that heavy metal concentrations in this study pose no health risk to children. Concentrations of all the heavy metals examined were below the critical limits for WHO, FEPA and EU. However, regular monitoring to avoid accumulation of heavy metals which can lead to health hazard is strongly recommended.

Keywords: Heavy Metal, Health Risk, Pollution Indices, Hazard Index, Playgrounds.

Introduction

Heavy metals are natural components of the earth crust. The accumulation and contamination of soils by heavy metals is a serious problem around the world due to its toxicity and persistence. Soils serve as a natural sink for heavy metals and are the critical environmental media where water, air and rock inter-face (Jonathan *et al.*, 2004). Some of the heavy metals that frequently occur in contaminated soils and potentially cause health problems include Iron (Fe), Chromium (Cr), Cadmium (Cd), Zinc (Zn), Copper (Cu) and Lead (Pb). Others include Arsenic (As), Mercury (Hg), Cobalt (Co), Nickel (Ni), Manganese (Mn), and Magnesium (Mg) (Okereke *et al.*, 2017).

Sources of heavy metals are both natural and anthropogenic and these sources include soil erosion, weathering, agrochemicals, mining, and waste discharges from homes and industries (Yahaya *et al.*, 2020). The occurrence of heavy metals in playground soils is normally linked to anthropogenic sources such as vehicular emissions, industrial effluents,

areas that are undergoing constructions and the combustion of biomass (Donado *et al.*, 2020). Since most playground soils are without vegetative cover, they act as suitable medium for heavy metal accumulation (Biose *et al.*, 2021). Heavy metals have been implicated in several health hazards, including respiratory, genetic and haematological diseases as well as skin, sight and brain damage (Yahaya *et al.*, 2020).

School playgrounds are areas around a school designed for children to play, make them merry, help improve their learning abilities, provide enjoyment, recreation, and develop physical fitness. Modern playgrounds are usually equipped with metal made sandbox, jungle gym, merry – go – round, slide and other materials to enhance recreational activities (Panteado *et al.*, 2021). However, several playgrounds have equipment that are either too old or not maintained adequately and these playgrounds are generally exposed to heavy metal contaminations from sources such as batteries, steel, wall paints etc. In addition, there is also the risks posed by industrial discharges and other sources resulting from situating schools in densely populated and industrialized areas (Okereke & Amadi, 2017).

According to European Environment Agency (2003), it is important to recognize and assess risks to human health and to children, in particular, from environmental hazards including heavy metals. Children are more susceptible to environmental hazards due to a number of factors including smaller body sizes, higher organ proximity and low heights (De-Mingeul *et al.*, 2007). The vulnerability of children to metal toxicity is further exacerbated by other factors including the fact that children's nervous and digestive system are still developing (Verla & Verla, 2017), children ingest more dust (pica) than adults and they have large surface to volume ratio (Popoola *et al.*, 2012).

Several studies have investigated heavy metal concentrations in playground soils across different regions. For example, Doku *et al.* (2018) studied playgrounds in Ghana, Tepanosyan *et al.* (2017) in Yerevan, Durowoju *et al.* (2018) in Lagos, Verla and Verla (2017) in Imo State, and Okereke & Amadi (2017) in Port Harcourt. In Edo State, however, only a few studies, such as Biose *et al.* (2021), have examined this issue. This limited research highlights a gap in knowledge regarding the extent of heavy metal contamination in primary school playgrounds within the state. It is against this background that this study attempts to quantify heavy metals concentrations in school playgrounds in Edo State and estimate their potential health risks to children who are the most vulnerable. Furthermore, this study seeks to provide baseline information that can be used as reference for further studies and to contribute information to the already existing literature in this research area.

Statement of Problem

Heavy metal contamination of soils poses a global public health challenge, and children are among the most vulnerable due to their developing organs, hand-to-mouth behavior, and higher exposure to dust. Primary school playgrounds, where children spend long hours, are particularly at risk.

Studies across Nigeria have revealed concerning levels of heavy metals in school environments. In Lagos, Cd, Cr, and Pb exceeded safety thresholds with significant cancer risks (Durowoju *et al.*, 2018). In Ibadan, children's blood Pb levels were directly linked to playground soil concentrations (Adebamowo *et al.*, 2006). Similar findings have been reported in Port Harcourt and Imo State (Okereke & Amadi, 2017; Verla & Verla, 2017). These results highlight the reality that school soils can serve as reservoirs of toxic metals, with direct implications for children's health.

Despite these concerns, little is known about playground soil contamination in Edo State, where industrial activity, urban traffic, and poor waste management may increase risks. The absence of localized data creates a critical gap, preventing targeted interventions and policies to protect schoolchildren.

This study therefore seeks to fill this gap by quantifying heavy metal concentrations in playground soils across Edo State, assessing associated health risks, and providing baseline data for environmental health management in the region.

Objectives of the Study:

This study aims to:

1. Quantify the concentrations of selected heavy metals in topsoil samples from primary school playgrounds in Edo State.
2. Evaluate the potential health risks associated with children's exposure to heavy metals in these playgrounds.
3. Provide baseline data that can serve as a reference for future research and policy development on environmental health in the region.

Literature Review

Popoola (2012) conducted a study on the concentrations of heavy metals in playground topsoil of some public primary schools in Lagos. The purpose of the study was to ascertain whether the levels of heavy metals in the soil were high enough to endanger children. Soil samples were obtained from 20 schools in Lagos and were analyzed using standard methods. The investigation revealed that Pb has the highest concentrations of all the metals. Mean metal concentration in playground soils were Pb_{HD} 23.08±11.11, Pb_{LD} 23.54±14.55; Cr_{HD} 5.99±5.79, Cr_{LD} 3.80±3.83; Cd_{HD} 0.33±0.33, Cd_{LD} 0.39±0.31; Mn_{HD} 1.60±0.14, Mn_{LD} 1.61±0.05 µg/g. Univariate analysis of variance showed that the metal concentrations in the high or low population density areas were not significantly different ($p>0.05$). The results generally indicated that pollution by metals in the dusts and soils is minimal for Pb and Cr and negligible for Mn and Cd while geographical location of the schools in high and low population density areas of Lagos state, Nigeria was not a determinant in the evaluation of children's exposure to heavy metals.

Okereke & Amadi (2017) conducted a study in Port Harcourt Metropolis assessing heavy metal concentrations in school playgrounds. Soil samples were collected from ten (10)

different school playground and analysis was carried out using standard methods. The assessment showed that concentration of heavy metals in this order $\text{Fe} > \text{Zn} > \text{Cr} > \text{Cu} > \text{Co} > \text{Pb} > \text{Ni} > \text{Mn} > \text{Cd} > \text{As} > \text{Hg}$. Extent of contamination and metal pollution source were evaluated using geoaccumulation index and pollution load, contamination and enrichment factors revealed that the sampling sites were classified either as low level of pollution or unpolluted and fall within the background values. Result also revealed that there was moderate Mn contamination in all the school playgrounds; while others exhibit moderate contamination levels. There was variation in the deposition sources of heavy metals from one metal to another and from one school to another. The result also revealed that Zn and Mn deposition had natural origin. While, Cu, Cr and Fe in most of the playgrounds were from anthropogenic sources. Risk assessment revealed the existence of heavy metals in school playgrounds were within acceptable levels. Thus, it is necessary to carry out periodic monitoring of these playgrounds to ensure the safety of school children.

Durowoju *et al.* (2018) carried out a study on health risk assessment of heavy metals on primary school learners from dust and soil within school premises in Lagos State. Heavy metal concentrations were analyzed using standard methods. Results of the study revealed that some of the heavy metals were above the threshold set up by WHO, FEPA and DPR. The soil was contaminated with Pb, Cd and Cr while Mn was within the threshold. The estimation of hazardous index (HI) for non-carcinogenic and/or carcinogenic risks in children was carried out and the HI values showed that heavy metal pollution may constitute no visible non-cancer health risk to children attending those schools. However, the greatest carcinogenic risk exposure pathway is through ingestion, accompanied by inhalation. It was found that the cancer risk for learners was 3.2×10^{-2} (1 in 31 individuals). Thus, it is necessary for the authorities to be aware of the health risks posed by heavy metals in school playgrounds.

Javed *et al.* (2019) conducted a risk – based exposure evaluation for several heavy metals encountered by children in school playgrounds and parks in the southwest region of Saudi Arabia. The study opined that children are in direct contact with surface soil and may unintentionally inhale and ingest heavy metals while playing. Thus, attention needs to be focused on playgrounds regarding harmful contaminants. Levels of heavy metals were determined in samples of soil obtained from school playgrounds and children's parks from the South West region of Saudi Arabia. Sample analysis was carried out using standard methods. Results showed that the soils had moderate pH in the range of 7.6 – 8.8, sand particles (54 – 88%) was dominant in the texture and the range of organic matter was between 2.06 – 4.82%. Heavy metal concentrations were as follows; 0.014 – 0.087, 1.14 – 3.54, 0.85 – 23.29, 0.77 – 36.32, 312.6 – 2065.7, 285.3 – 822.6, 75.4 – 240.8, 0.00 – 53.12, 0.52 – 6.80, and 1.25 – 92.12 mg/kg dry soil for Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, and Zn, respectively. These values were lower than the permissible limits, showing insignificant impact of man – made activities and can be categorized as unpolluted soil. Contamination factor and enrichment coefficient were below one (1) which indicates that the source of

these metals was majorly the local soil. However, Zn and Ni in some playgrounds were the contamination factor were higher than 1 suggesting that contamination originated from external sources. The calculated non – carcinogenic hazard index for all the metals was lower than 1, suggesting that heavy metal exposure through playground soil will not have any deleterious effects on children using these playgrounds.

Guo *et al.* (2020) conducted a study on contamination, distribution and health risk assessment of heavy metals in topsoil for amusement parks in China. The pollution level was evaluated using the pollutant load index (PLI) and the index of geo-accumulation (I_{geo}), and the health risk for children was calculated using the U.S. Environmental Protection Agency's (EPA) health risk model. Additionally, a geographic information system (GIS) was used to map the distribution features of the contents of the risk factors. According to the findings, (1) each park had the greatest mean Mn concentration. Additionally, each park's background value of Shaanxi was surpassed by the mean content of all heavy metals except As. The Xing Qing Park (XQP) had the greatest (4.07) content, and the I_{geo} of Co was clearly higher than other elements in each park. In comparison to the other four parks, the Urban Sports Park (USP) had the worst pollution. (3) The children's oral intake made them more vulnerable to heavy metal contamination. The carcinogenic risks (CR) of Cr, Ni, As, and Co for children were within the permissible range in each park, and the hazard indices (HI) of non-carcinogenic risk (NCR) were within the safe range (HI = 1).

Biose *et al.* (2021) carried out a study on heavy metal contents in topsoils of selected public primary schools playgrounds in Benin metropolis, Nigeria. The mean concentrations for heavy metals ranged from 337.15 ± 64.28 and 464.10 ± 19.37 for Fe, 23.40 ± 7.50 and 29.70 ± 4.81 for Mn, 45.95 ± 8.70 and 67.95 ± 4.74 for Zn, 8.48 ± 1.61 and 12.90 ± 3.82 for Cu, 5.10 ± 2.33 and 7.41 ± 1.54 for Cd, 4.42 ± 2.02 and 8.39 ± 7.09 for Cr, 6.17 ± 2.82 and 13.82 ± 6.76 for Pb, 0.99 ± 0.09 and 3.24 ± 3.73 for Ni respectively. Heavy metal concentrations were in the following order. In Ogiegbaen, Eresoyen and Ekosodin Primary schools (PS) playground, the order was Fe > Zn > Mn > Cu > Pb > Cd > Cr > Ni while the order in Agbado PS and Olua PS were Fe > Zn > Mn > Cu > Pb > Cr > Cd > Ni and Fe > Zn > Mn > Pb > Cu > Cd > Cr > Ni respectively. Enrichment factor (EF), Contamination factor (CF) and Geoaccumulation index (I_{geo}) were used to evaluate the pollution status of the soil. In their study, Heavy metals concentrations were low when compared with the values obtained elsewhere in the world.

Zgłobicki *et al.*, (2021) conducted a study in Poland on heavy metals concentrations in playgrounds. The study evaluated sources, levels of pollution and health risks. The study opined that the most vulnerable group are children and it is very important to investigate the extent of pollution and associated health hazards. 50 playgrounds were assessed and soil samples were obtained from three types of areas namely: soil in the playgrounds, soil under the swings and soil in the sandpits. heavy metal concentrations were determined in the < 0.05-mm fraction. The mean concentrations of heavy metals were Cd - 4.7 mg kg^{-1} , Cr - 192.4 mg kg^{-1} , Cu - 16.3 mg kg^{-1} , Hg - 0.027 mg kg^{-1} , Ni - 12.7 mg kg^{-1} , Pb - 41 mg kg^{-1} , and Zn

- 79.8mgkg^{-1} and they were in the following order when normalized to the geochemical background: $\text{Cd} > \text{Cr} > \text{Zn} > \text{Pb} > \text{Hg} > \text{Ni} > \text{Cu}$. The highest concentrations were observed in soil obtained under the swing (Cd, Cr, Ni and Zn) or soil (Cu, Hg and Pb) in the playgrounds. Geochemical indices such as index of geoaccumulation and enrichment factor showed no pollution or low levels of pollution with Cu, Cr, Ni Zn and Pb. Moderate pollution with Cd and high pollution with Hg. There was significant ecological risk in all samples as a result of Cd. In all the samples analyzed, the values of health hazard indices (HI, CR) for children are very low and well below the hazard threshold for each element.

Parlak *et al.* (2022) conducted a study on heavy metals in soil and sand from playgrounds of Canakkale City (Turkey) and associated health risks for children. The study presented a comparative analysis of heavy metal concentrations between soils and sand from sand boxes obtained from playgrounds of Canakkale City. Average concentrations of heavy metal in soil were in the following order iron (Fe) ($12,901\text{ mg kg}^{-1}$) > manganese (Mn) (475 mg kg^{-1}) > zinc (Zn) (58 mg kg^{-1}) > copper (Cu) (28 mg kg^{-1}) > nickel (Ni), chromium (Cr) (21 mg kg^{-1}) > lead (Pb) (18 mg kg^{-1}). Sand exhibit lower concentrations, however, as a result of reduction of particle size through prolonged use and accumulation of Fe/Mn on sand grains tend to diminish the differences between soil and sand. Chemometric analysis showed that Cr and Ni had lithogenic origin while the rest of the metals were caused by man – made activities. Children’s health risks estimation showed that ingestion was the most important route of exposure accompanied by dermal contact and inhalation. These findings are relevant because the sand contamination has not received much attention in comparison to playground spoils.

Doku *et al.* (2023) carried out a study on heavy metal contamination and related health risks of school playground in the Sunyana – East municipality of Ghana. Heavy metal concentrations such as Cu, Fe, Mn, Zn, Pb, Cd and As in schools playground soils were analyzed using standards methods. Variables and relationship between heavy metals were conducted using Person’s correlation and Principal Component Analysis. The enrichment factor, index of geoaccumulation, contamination factor and pollution load index were calculated to evaluate the degree of pollution by heavy metals. Children’s associated health risks were assessed using hazard index and hazard quotients. The results showed high concentration of Fe ($12,093.33 - 40,026.67\text{ mg/kg}$), Cd ($0.60 - 11.43\text{ mg/kg}$) and Cu ($31.92 - 85.00\text{ mg/kg}$) in soils of most schools’ playground which were above permissible limits. Cd, Pb and As, had strong correlations which formed one principal component caused by man – made sources. Enrichment and Contamination factor indicate high pollution of playgrounds with As, Fe, Cd and Cu. The hazard index of playground soils in some schools showed health risks to children. Potential health effects in children were caused by As, Fe and Cd hence, showing that these playgrounds are unsuitable for children to use. Therefore, the study suggests that measures need to be taken to avert the deleterious effects of heavy metals in children attending those schools.

Kyene (2023) carry out a study on bioaccessibility and children health risk assessment of soil-laden heavy metals from school playground and public parks in Accra, Ghana. The study opined that the high exposure rate of parks and playground soils makes them a significant matrix for children's exposure to harmful substances. One hundred and twenty (120) soil samples were collected between April 2015 and March 2016 and then analyzed for heavy metals. Using the hazard index and oral bioaccessibility, the health risk that heavy metals in soil posed to school children was evaluated. Using the simple bioaccessibility extraction test (SBET) method, the metals' oral bioaccessibility was calculated. Iron (Fe) measured the highest range of total metal concentrations of 2785.0–15275.0 mg kg⁻¹ followed by Pb of 2.1–284.0 mg kg⁻¹. The oral bioaccessibility of the metals varied significantly with Pb and Cu exhibiting the highest mean values of 47.80% and 54.45%, respectively. The mean concentration of metals in the soil does not match the sequence for the mean bioaccessibility result. With the exception of Pb, the hazard index (HI) for the majority of heavy metals showed no possible non-carcinogenic health harm to children (HI < 1). Its elevated risk may be explained by the long-term usage of leaded fuel in Ghana before it was completely banned on January 1, 2004, as well as the persistence of lead in soil media. In order to reduce children's exposure to heavy metals found in soil, playground environmental management must be adopted and implemented due to the detrimental health effects of lead on kids.

Materials and Methods

Study Area

This research was conducted in 3 out of the 18 Local Government Areas of Edo State namely Orhiomwon (Station 1), Uhunmwode (Station 2) and Ikpoba-okha (Station 3). Edo State is situated at latitude 6.6342°N and longitude 5.9304°E in the southern region of Nigeria. It has a total land area of 17,802km² and a tropical climate with two distinct seasons, rainy and dry season. The rainy season begins in March/April and ends in October/November, while the dry season begins in November/December and ends in February/March. Rainfalls are of high intensity and usually double maxima with a dry little spell in August referred to as 'August break' which last for about 2 - 3 weeks and a windy harmattan period during December /January. The map of the study area showing sampling stations is presented in figure 1 below.

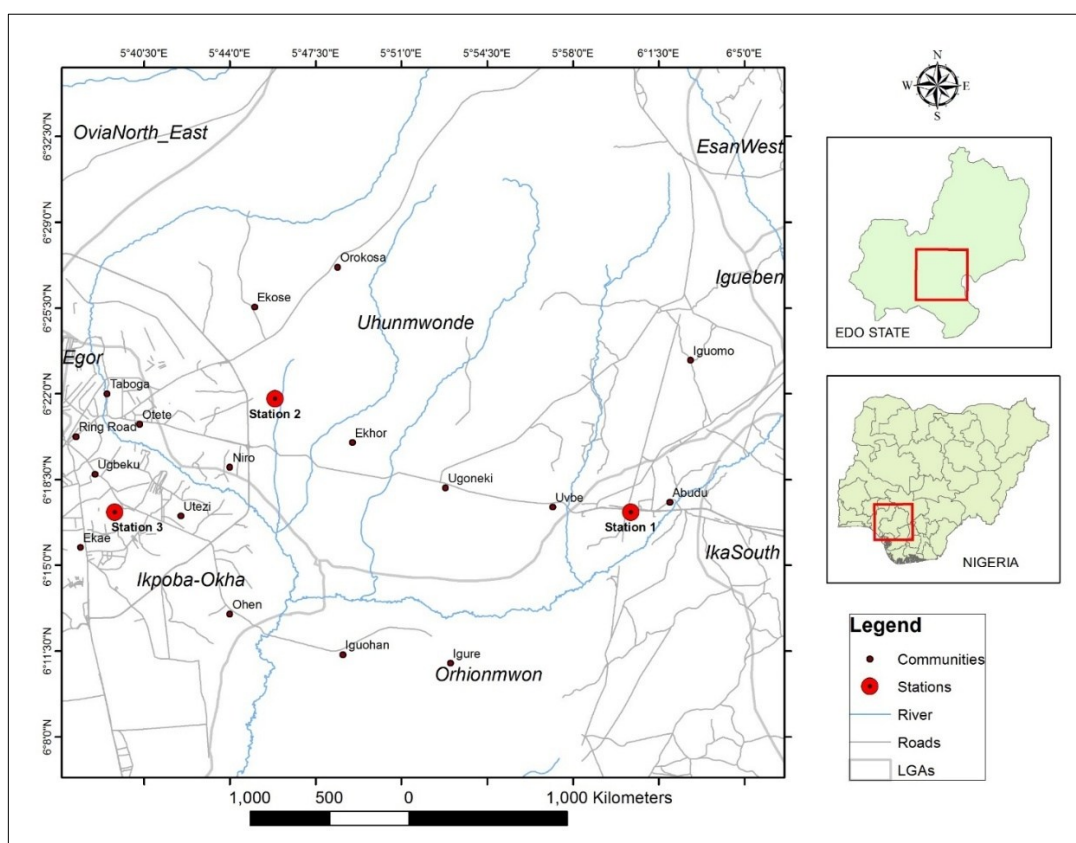


Figure 1: Map showing the points of sample collection

Study Design

This study adopted a cross-sectional design focusing on three Local Government Areas (LGAs) of Edo State which are Orhionmwon, Uhunmwode, and Ikpoba-Okha. These LGAs were selected because they represent urban, peri – urban and rural settings. Ikpoba-Okha represents a highly urbanized and industrialized part of Benin City, characterized by heavy traffic, residential density, and industrial activities. Uhunmwode represents a peri-urban transition zone where agricultural activities mix with expanding residential settlements. Orhionmwon represents a more rural area, dominated by subsistence farming and less industrialization. This stratified selection allows for comparison across different land-use settings and potential exposure pathways for heavy metals. Also, because of paucity of funds and given the resource-intensive nature of soil sampling, laboratory digestion, and AAS analysis, three LGAs were strategically chosen to balance feasibility with adequate coverage. This approach aligns with earlier playground studies in Nigeria (e.g., Biose *et al.*, 2021 in Benin; Durowoju *et al.*, 2018 in Lagos) that also used representative sub-areas rather than full State coverage. Furthermore, these LGAs host a large proportion of public primary schools and children from diverse socio-economic backgrounds. Findings from them can serve as a reliable proxy for assessing risks across the state and provide baseline data for future large-scale assessments.

Sample Collection, Preparation and Analysis

Soil samples were collected randomly from primary school playgrounds. The point of collection of the samples included spots where children played during breaks in the playgrounds. Homogenized soil samples from three different points were collected at the depth of 0-10cm using a hand trowel and transferred into black polythene bags and labeled. Three soil samples were collected from each of the school playground and bulked to form a composite sample. Overall, 9 samples were collected from the study area in the month of April representing 3 samples per Local Government Area. The bags were tied tightly and transported to the laboratory for analysis.

In the laboratory, soil samples were bulked, air dried at room temperature between 25°C - 27°C for two to three days and debris was removed. Samples were pulverized and digested using the aqua-regia (HCl + HNO₃ in 3:1) wet digestion described by Likuku *et al.* (2013). Subsequently, the concentrations of Lead (Pb), Cadmium (Cd), Nickel (Ni), Chromium (Cr), Iron (Fe), Copper (Cu), Zinc (Zn) and Manganese (Mn) in the digested samples were determined using Atomic Absorption Spectrophotometer (AAS) (Buck Scientific, model 210VGP).

Quality Assurance and Quality Control

To ensure accuracy and reliability of the analytical results, the following QA/QC protocols were implemented:

- **Blanks:** Reagent blanks were processed alongside samples to check for contamination during digestion and analysis.
- **Replicates:** At least 10% of the samples were digested and analyzed in duplicate to assess precision.
- **Calibration:** The AAS was calibrated with multi-element standard solutions (prepared from 1000 mg/L stock solutions) at five concentration levels before sample analysis. Calibration curves with correlation coefficients (R^2) > 0.995 were accepted.
- **Detection Limits:** Method detection limits (MDLs) and limits of quantification (LOQs) for each element were determined according to USEPA (2005).
- **Recovery Test:** A certified reference material (soil standard, where available) was digested in parallel with samples, and recovery values between 85%–110% were considered acceptable.

Statistical Analysis

Data obtained in this study were evaluated using statistical analysis to characterize the samples. The significant difference in the chemical conditions was tested using parametric analysis of variance (ANOVA). All data analyses including Contamination Factor (CF), Pollution Load Index (PLI) and Geo-accumulation index (I_{geo}) were done using Microsoft excel (2003) window application and SPSS version 20.00.

Assessment of Soil Contamination (pollution indices)

Contamination Factor (CF): contamination factor was used to quantify the degree of contamination of heavy metals in soil. The sum of contamination factors for all elements examined represents the contamination degree (C_{deg}) of the environment. Contamination factor is expressed as follows:

$$C = \frac{C_{metal}}{C_{background}}$$

Where C_{metal} is the concentration of a metal in the studied samples and $C_{background}$ is the background concentration of that metal in the soil. Four classes of C_{deg} are recognized (Okereke *et al.*, 2017). $C_{deg} < 8$ low degree of contamination, $8 \leq C_{deg} < 16$ moderate degree of contamination, $16 \leq C_{deg} < 32$ considerable degree of contamination, $32 \leq C_{deg}$ very high degree of contamination.

According to Hakanson (1980), $CF < 1$ implies low contamination; If $1 < CF < 3$ moderate contamination exists; If $3 < CF < 6$ it implies that considerable contamination exists; $CF > 6$ implies very high contamination.

Pollution Load Index (PLI): Pollution Load Index was used to access the extent of heavy metal pollution in soil. PLI helps to compare the pollution levels between sites at different times. PLI can be expressed as:

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n}$$

Where, CF represents the contamination factor (CF), and n represents number of metals. When $PLI > 1$, it means that pollution exists; otherwise, if $PLI < 1$, no pollution exists.

Table 1: The Classification Standards for PLI (Geo *et al.*, 2020).

Classification	PLI	Pollution Level
0	$PLI < 1$	Not contaminated
1	$1 \leq PLI < 2$	moderately contaminated
2	$2 \leq PLI < 3$	Heavily contaminated
3	$PLI \geq 3$	Extremely contaminated

Index of Geo-accumulation: Geo-accumulation index was used to quantify the degree of contamination and compare the concentration of different heavy metals in soil sample. Geo-accumulation index makes it possible to compare the measured concentration of heavy metals in soil sample (current status) with the geochemical background values (pre-industrial concentrations) (Muller, 1979). I_{geo} is expressed as:

$$I_{geo} = \log_2 \frac{C_n}{1.5 \times B_n}$$

Where C_n is the concentration of each heavy metal in soil, B_n is the average concentration of heavy metals in soil (the average value considered as reference point or background value), K is a constant value and equals 1.5, which refers to natural fluctuations of a given heavy metal in the environment due to lithological variations. According to Adimalla and Wang (2018) the I_{geo} for each metal is calculated and classified as Class 0 - practically

uncontaminated ($I_{geo} \leq 0$); Class 1 - uncontaminated to moderately contaminated ($0 < I_{geo} \leq 1$); Class 2 - moderately contaminated ($1 < I_{geo} \leq 2$); Class 3 - moderately to heavily contaminated ($2 < I_{geo} \leq 3$); Class 4 - heavily contaminated ($3 < I_{geo} \leq 4$); Class 5 - heavily to extremely contaminated ($4 < I_{geo} \leq 5$); Class 6 - and extremely contaminated ($I_{geo} \geq 5$).

Health Risk Assessment of Heavy Metals in Soil

Health risk assessment of heavy metals in soil was estimated through ingestion, inhalation and dermal pathways. The United States Environmental Protection Agency (USEPA, 2005) method of risk assessment was applied in this study for the health risk assessment. Health risk assessment was used to determine the carcinogenic and non-carcinogenic risks due to chemical exposure (Adimalla & Wang, 2018). The average daily dose (ADD) in milligram per kilogram per day (mg/kg/day) values of heavy metals through ingestion, inhalation and dermal pathways was computed using the following equations:

$$ADD_{ing} = \frac{CMS \times IR \times ED \times EF}{ABW \times AET} \times CF$$

$$ADD_{inh} = \frac{CMS \times IHR \times ED \times EF}{ABW \times AET \times PEF} \times CF$$

$$ADD_{dermal} = \frac{CMS \times SA \times SAF \times DAF \times EF \times ED}{ABW \times AET} \times CF$$

Where CMS is the concentration of metal in soil (mg/kg), IR and IHR are the ingestion and inhalation rates, respectively (mg/day); EF and ED represent exposure frequency (365 days/year) and exposure duration (6 years) respectively; SA is exposed skin surface area (cm²); SAF is the skin adherence factor (kg/cm² day); ABW and AET represent the average body weight (kg) and average exposure time period (year), respectively. CF is the conversion factor (10⁻⁶ kg/mg), DAF is the dermal absorption factor (0.001), and PEF is the particle emission factor (1.36 × 10⁹ m³/kg).

The non-carcinogenic risk (Hazard Quotient - HQ) of the various heavy metals implicated in this study was computed via the various exposure pathways (ingestion, inhalation and dermal) as the ratio of ADD to reference dose (Rfd) of each metal for each pathway. Expression as:

$$HQ = \frac{ADD}{RfD}$$

HQ < 1 indicates no adverse health effect, while HQ > 1 indicates that detrimental health effects are likely to occur. Table 2 below presents the Rfd for some heavy metals.

Table 2: The reference Rfd of Heavy Metals (Jafari *et al.*, 2019; Wang *et al.*, 2019)

Metal	RfD _{ing} (mgkg ⁻¹ day ⁻¹)	RfD _{inh} (mgkg ⁻¹ day ⁻¹)	RfD _{der} (mgkg ⁻¹ day ⁻¹)
Cr	3.00E-03	2.86E-05	6.00E-05
Ni	2.00E-02	2.06E-02	5.40E-03
Cu	4.00E-02	4.02E-02	1.20E-02
Pb	3.50E-03	3.52E-03	5.25E-04
Zn	3.00E-01	3.00E-01	6.00E-02

The Hazard Index (HI) is equal to the sum of all expected non-carcinogenic risks (HQs) through ingestion, inhalation and dermal pathways and was employed to compute the total potential non-carcinogenic risks of the different heavy metals through 3 exposure pathways (ingestion, inhalation and dermal).

$$HI = HQ_{\text{ingestion}} + HQ_{\text{inhalation}} + HQ_{\text{dermal}}$$

Value of $HI < 1$ indicates no significant risk of non-carcinogenic effects is deemed to occur. $HI > 1$, indicates a possibility of non-carcinogenic effects, and the possibility increases as HI value increases.

Ethical Considerations

Permission to conduct soil sampling was obtained from the Edo State Ministry of Education and the head teachers of the selected schools. No children participated directly in the study, and all sampling was carried out in designated safe areas to avoid disrupting academic activities or exposing children to hazards. The research protocol complied with the ethical guidelines for environmental and public health research established by the University of Benin.

Results

Heavy metal concentrations

The occurrence of heavy metals in all three stations is summarized in table 3 below.

Table 3: Summary Table of Heavy metals in playground soils

Heavy metals	Station 1	Station 2	Station 3	P value
	Mean±SD (Min – Max)	Mean±SD (Min – Max)	Mean±SD (Min – Max)	
Lead	ND	0.01±0.01 (0.00 – 0.02)	ND	$p > 0.05$
Cadmium	ND	ND	ND	
Nickel	0.16±0.14 (0.08 – 0.33)	0.11±0.04 (0.06 – 0.14)	0.14±0.05 (0.09 – 0.18)	$p > 0.05$
Chromium	0.06±0.05 (0.00 – 0.10)	0.06±0.05 (0.03 – 0.12)	0.11±0.07 (0.04 – 0.17)	$p > 0.05$
Iron	16.57±3.39 (12.90 – 19.60)	18.40±0.98 (17.60 – 19.50)	18.87±1.03 (18.00 – 20.00)	$p > 0.05$
Copper	0.01±0.02 (0.00 – 0.04)	0.02±0.02 (0.00 – 0.03)	0.01±0.01 (0.00 – 0.02)	$p > 0.05$
Zinc	1.55±0.44 (1.18 – 2.04)	1.45±0.61 (0.84 – 2.06)	0.27±0.11 (0.15 – 0.37)	$p < 0.05$
Manganese	0.81±0.49 (0.34 – 1.32)	1.12±0.30 (0.86 – 1.45)	1.24±0.68 (0.84 – 2.02)	$p > 0.05$

Station 1 – Orhiomwon; Station 2 – Uhunwmode; Station 3 – Ikpoba Okha; ND – Not Detected

The order of occurrence of heavy metal across the sampling stations is as follows - Station 1: Fe > Zn > Mn > Ni > Cr > Cu > Pb; Station 2: Fe > Zn > Mn > Ni > Cr > Cu > Pb; and Station 3: Fe > Mn > Zn > Ni > Cr > Cu > Pb.

The analysis of the correlation among all the heavy metals analyzed in this research is presented below in table 4. It reveals that Fe is strongly positively correlated with Ni (0.940) at $p < 0.01$. Cu is strongly positively correlated with Ni (0.828) and Fe (0.828) at $p < 0.01$. Mn is strongly positively correlated with Fe (0.810) at $p < 0.01$. Mn is positively correlated with Ni (0.688) and Cu (0.695) at $p < 0.05$.

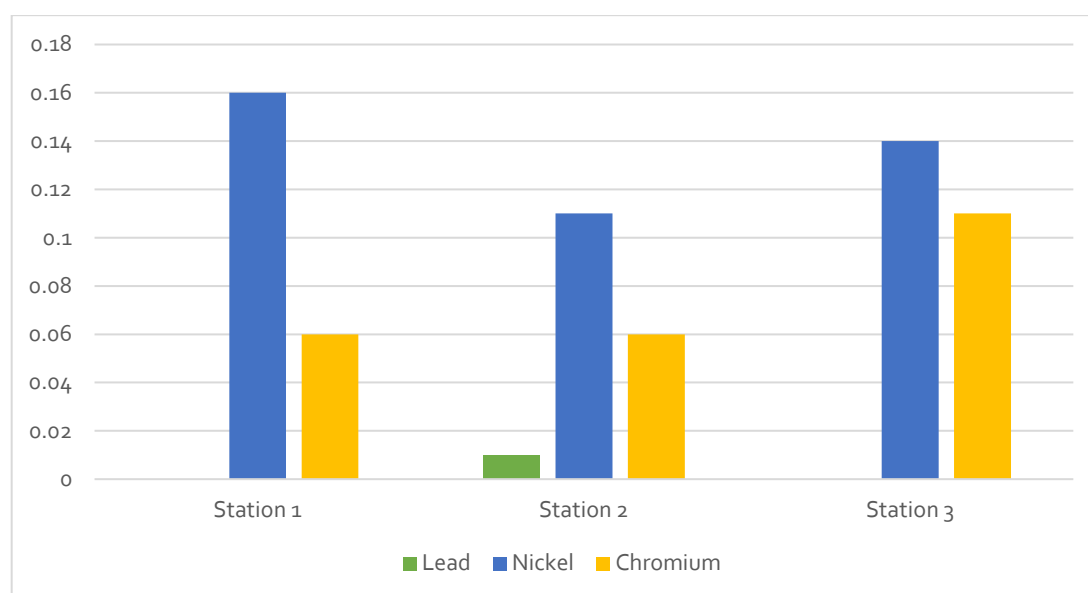


Figure 1: Concentrations of Lead, Nickel and Chromium across station

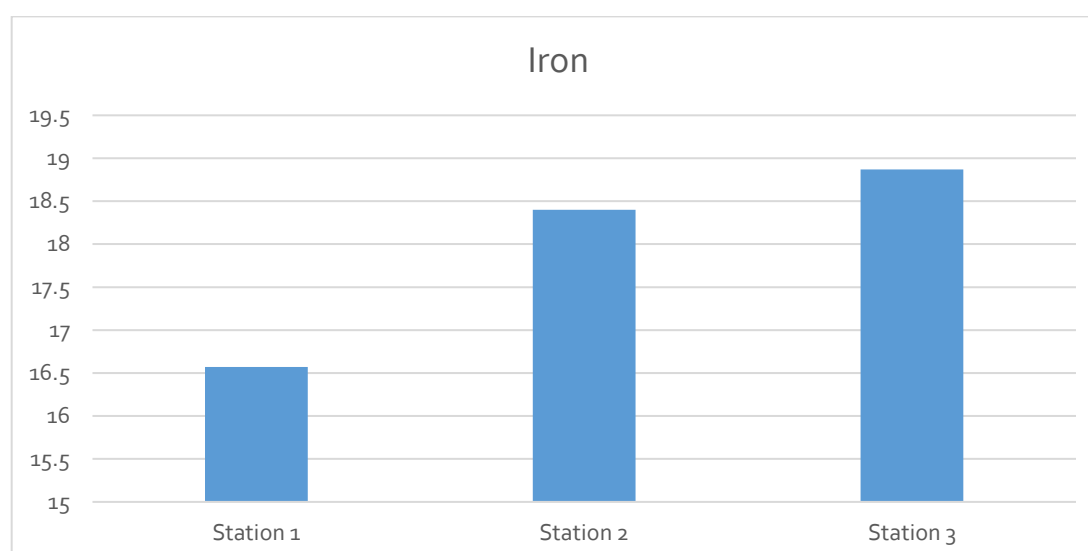


Figure 2: Concentrations of Iron across stations

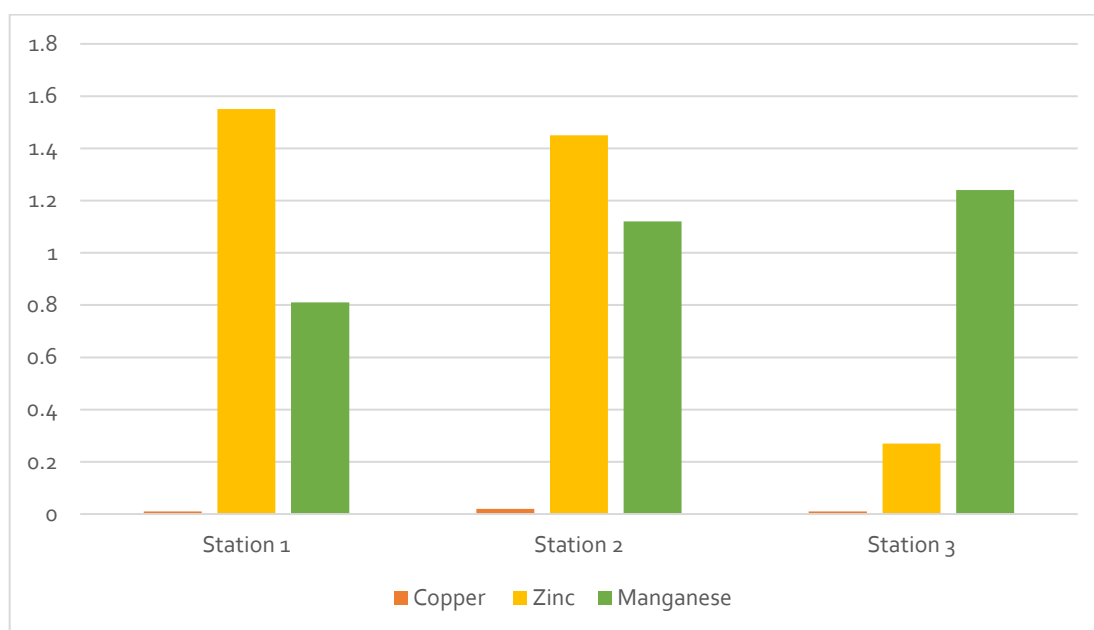


Figure 3: Concentrations of Copper, Zinc and Manganese across stations

Table 4: Correlation matrix of heavy metals in the soil

	Pb	Cd	Ni	Cr	Fe	Cu	Zn	Mn
Pb	1							
Cd	. ^a	. ^a						
Ni	-.035	. ^a	1					
Cr	-.136	. ^a	.353	1				
Fe	.111	. ^a	.940**	.473	1			
Cu	-.112	. ^a	.828**	.455	.828**	1		
Zn	.265	. ^a	.176	.025	.304	.435	1	
Mn	.003	. ^a	.688*	.596*	.810**	.695*	.144	1

** Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

Pollution assessment of heavy metal contamination

The result of the pollution load index, contamination factor, contamination degree is shown in table 5 below.

Table 5: Pollution indices of metals in the various stations

Heavy metals	Station 1	Station 2	Station 3
Contamination Factors			
Nickel	0.0046	0.0031	0.0040
Manganese	0.0010	0.0013	0.0015
Copper	0.0003	0.0006	0.0003
Zinc	0.0111	0.0104	0.0019
Iron	0.0004	0.0005	0.0005
Chromium	0.0006	0.0006	0.0011
Contamination degree	0.0179	0.0165	0.0093
Pollution Load Index	0.0010	0.0010	0.0010

The index of geoaccumulation of heavy metals in the playground soils of the various stations studied is shown below in table 6.

Table 6: Index of geoaccumulation of heavy metals in the soils

Heavy metals	Station 1	Station 2	Station 3
Nickel	-9.316	-9.857	-6.362
Manganese	-10.620	-10.153	-10.152
Lead	ND	-11.551	ND
Cadmium	ND	ND	-5.492
Copper	-12.721	-11.721	-7.966
Zinc	-6.523	-6.619	-2.917
Iron	-12.024	-11.873	-19.259
Chromium	-11.136	-11.136	-11.136

Non-Carcinogenic Risk (NCR) Assessment

The result of Non-Carcinogenic Risk (NCR) assessment of heavy metals in all the stations is presented in table 7, 8 and 9 below.

Table 7: Human Health risk assessment of heavy metal contamination in Station 1

Heavy metals	CDI _{ingestion}	CDI _{inhalation}	CDI _{dermal}	HQ _{ingestion}	HQ _{inhalation}	HQ _{dermal}
Nickel	2.13E-06	7.84E-11	5.97E-09	1.07E-04	3.81E-09	1.11E-06
Manganese	1.08E-05	3.97E-10	3.03E-08	7.71E-05	2.84E-09	2.16E-07
Copper	1.33E-07	4.90E-12	3.73E-10	3.33E-06	1.23E-09	3.11E-08
Zinc	2.07E-05	7.60E-10	5.79E-08	6.89E-05	2.53E-09	9.64E-07
Iron	2.21E-04	8.12E-09	6.19E-07	3.16E-04	1.16E-08	8.84E-07
Chromium	8.00E-07	2.94E-11	2.24E-09	2.67E-04	1.03E-06	3.73E-05
			HI	8.38E-04	1.05E-06	4.05E-05
			THI	8.80E-04		

HI – Hazard Index, THI – Total hazard index

Table 8: Human Health risk assessment of heavy metal contamination in Station 2

Heavy metals	CDI _{ingestion}	CDI _{inhalation}	CDI _{dermal}	HQ _{ingestion}	HQ _{inhalation}	HQ _{dermal}
Nickel	1.47E-06	5.39E-11	4.11E-09	7.33E-05	2.62E-09	7.60E-07
Manganese	1.49E-05	5.49E-110	4.18E-08	1.07E-04	3.92E-09	2.99E-07
Copper	2.67E-07	9.80E-12	7.47E-10	6.67E-06	2.45E-09	6.22E-08
Zinc	1.93E-05	7.11E-10	5.41E-08	6.44E-05	2.37E-09	9.02E-07
Iron	2.45E-04	9.02E-09	6.87E-07	3.50E-04	1.29E-08	9.81E-07
Chromium	8.00E-07	2.94E-11	2.24E-09	2.67E-04	1.03E-06	3.73E-05
			HI	8.68E-04	1.05E-06	4.03E-05
			THI	9.10E-04		

HI – Hazard Index, THI – Total hazard index

Table 9: Human Health risk assessment of heavy metal contamination in Station 3

Heavy metals	CDI _{ingestion}	CDI _{inhalation}	CDI _{dermal}	HQ _{ingestion}	HQ _{inhalation}	HQ _{dermal}
Nickel	1.87E-06	6.86E-11	5.23E-09	9.33E-05	3.33E-09	9.68E-07
Manganese	1.65E-05	6.08E-10	4.63E-08	1.18E-04	4.34E-09	3.31E-07
Copper	1.33E-07	4.9E-12	3.73E-10	3.33E-06	1.23E-09	3.11E-08
Iron	2.52E-04	9.25E-09	7.04E-07	3.59E-04	1.32E-08	1.01E-06
Zinc	3.6E-06	1.32E-10	1.01E-08	1.20E-05	4.41E-10	1.68E-07
Chromium	1.47E-06	5.39E-11	4.11E-09	4.89E-04	1.89E-06	6.84E-05
			HI	1.08E-03	1.91E-06	7.09E-05
			THI	1.15E-04		

HI – Hazard Index, THI – Total hazard index

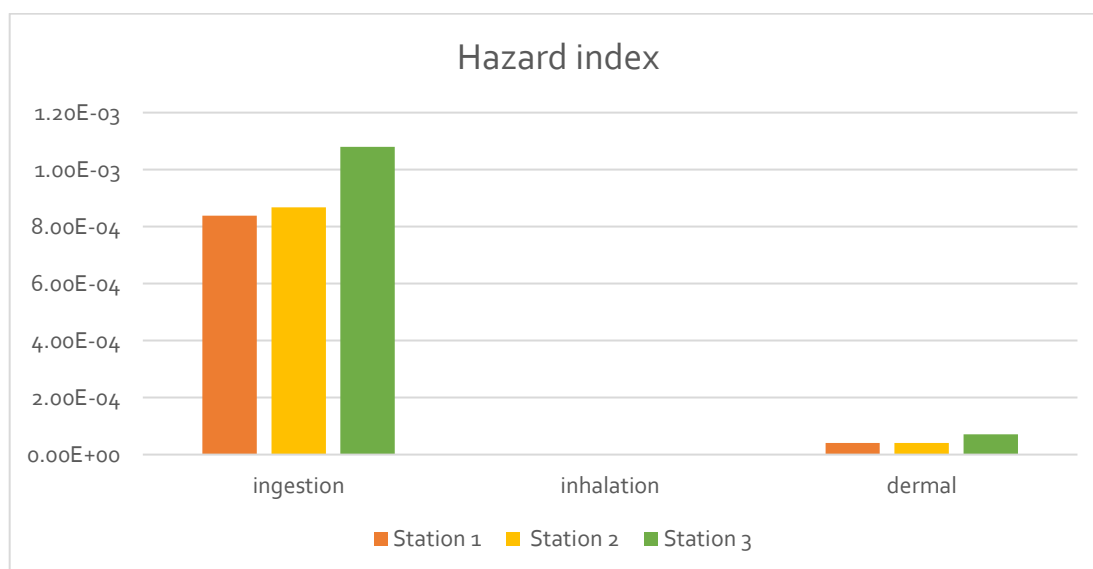


Figure 4: Hazard index of different exposure route

Discussion

Heavy metal concentrations

The main heavy metals encountered in the school playgrounds were Pb, Ni, Cr, Fe, Cu, Zn, Mn. Cd was not detected in all stations because the concentration of Cd was lower than the detection limit of the device. Lead was not detected in all the stations except station 2. Lead concentration in station 2 was lower than Pb permissible limits set by Federal Environmental Protection Agency (FEPA), and also lower than the concentrations of lead in primary school playgrounds in Benin City as studied by Biose *et al* (2021). Verla *et al.* (2015a), also reported higher Pb concentrations in soils of playgrounds within Owerri metropolis, Imo State. The reason for low concentration of lead in station 2 of the present study could be link to the fact that lead has been banned as additives in many products such as paints, fuels etc. The non-detectable level of Cd recorded in this study was because the primary schools were not located close to the sources of Cd. The possible sources of Cd in soil includes, burning plastic components of automobiles, pipes and tobacco smoke (Verla *et al.*, 2015b). Similarly, Javed *et al.* (2019) also reported Cd as the least heavy metal in school playgrounds and parks in the southwest region of Saudi Arabia. Fe has the highest concentration of all the heavy metal in all the stations. This observation contradicted the record of Verla *et al.* (2015b) which had zinc as the dominant heavy metal in playgrounds of public schools within Owerri Metropolis, Imo State. This difference can be attributed to spatial and geological compositional differences in the soil. The detection of Pb in Uhunmwode alone may be associated with localized sources such as old painted playground equipment, waste disposal, or vehicular emissions in peri-urban settings. However, Iron concentrations in all the stations were lower than the permissible limits set by FEPA and WHO. The concentrations of Fe found in the various soil samples were low when compared to the value obtained by De-Miguel *et al.* (2007) and Biose *et al.* (2021) in playground soils in Madrid, Spain and Benin City, Nigeria respectively.

higher Zn and Mn levels in Ikpoba-Okha may be linked to urbanization and traffic emissions, while relatively lower contamination levels in Orhionmwon suggest a rural background with minimal industrial influence (Verla and Verla, 2017; Yahaya *et al.*, 2020). These findings align with studies in Lagos (Durowoju *et al.*, 2018), where Pb and Cr were elevated in schools close to major roads, and in Ghana (Doku *et al.*, 2023), where Cd and Cu were strongly associated with anthropogenic inputs. In contrast, our results suggest lower anthropogenic input overall, which may be due to the less industrialized character of much of Edo State compared with large urban centers like Lagos or Port Harcourt.

The sources of heavy metals in playground soils are often both natural and anthropogenic. In this study, the dominance of Fe and Mn suggests primarily lithogenic origins. However, the presence of Pb and Zn, though at low levels, likely reflects anthropogenic inputs. Possible contributors include: Traffic-related emissions (Zn, Pb, Ni, Cu) from vehicular exhaust, brake and tire wear. Improper waste disposal and open burning around schools, which may release Pb, Cu, and Zn. Use of agrochemicals in peri-urban and rural areas,

contributing to Cr and Ni inputs. Old playground equipment and infrastructure (paints, galvanized metals, batteries) that can leach metals into soils (Okereke and Amadi, 2017). Such mixed sources are consistent with findings from other regions. For instance, Biose *et al.* (2021) in Benin metropolis reported Zn and Pb contamination linked to waste and paint sources, while Tepanosyan *et al.* (2017) in Yerevan attributed high Cr and Ni to both industrial and traffic-related emissions.

By and large the concentrations of all the heavy metals examined were below the critical limits for WHO, FEPA and EU. The analysis of variance (ANOVA) revealed that Ni, Cr, Fe, Cu, Mn had no significant difference across the stations ($p < 0.5$), while Zn showed a significant difference ($p < 0.5$) across the primary school playgrounds.

Pollution assessment of heavy metal contamination

Pollution assessment reveals that the highest and lowest contamination degree was in station 1 (Orhiomwon) and Station 3 (Ikpoba-okha) respectively, which suggests that station 3 is less contaminated by heavy metals.

Pollution load index (PLI) values across all the sampling location were all unpolluted with heavy metals as the values were less than 1. This suggests that anthropogenic activities in these areas are relatively low. In contrast, Biose *et al.* (2021) reported PLI values greater than 1 across all sampled stations, which they attributed to intense anthropogenic activities occurring near schools. Overall, Contamination Factors (CF), Contamination Degree (C_{deg}) and Pollution Load Index (PLI) of all the heavy metals calculated in this study were below one, which implies low contamination exists in all the playgrounds (Hakanson, 1980; Okereke *et al.*, 2017; Guo *et al.*, 2020).

The index of geoaccumulation of heavy metals was below zero for the metals in each station. Consequently, the concentrations of heavy metals recorded are below their background levels. Thus, playgrounds are practically uncontaminated and falls under Class 0 according to the classification given by Adimalla and Wang (2018) for index of geoaccumulation.

Non-Carcinogenic Risk (NCR) Assessment

The obtained results of non-carcinogenic health risk on children, based on metal concentrations in playgrounds soils and exposure by three different pathways (ingestion, inhalation, and dermal) in all the study locations are shown in Table 7, 8 and 9. The Hazard Quotient (non-carcinogenic risk) of the various heavy metals involved in this study was less than one for all the various exposure pathways (ingestion, inhalation and dermal) across all the stations which indicate no adverse health effects on children.

Hazard Index values were also less than one in all the stations for all the route of exposure (ingestion, inhalation and dermal) as shown in Figure 4. This suggest no significant risk of non-carcinogenic effects is deemed to occur from exposure to this metal in school playgrounds. Results also revealed that the major pathway of children exposure to heavy

metals in playground soils is via ingestion followed by dermal exposure. The inhalation pathway exposure was the least among the three routes of exposure. This finding supports other studies such as Acosta *et al.*, 2009; Durowoju *et al.* (2018), to establish the ingestion pathway as the major contributor to hazard index.

Conclusion

This study assessed the concentrations of heavy metals in playground soils of selected primary schools across three Local Government Areas (LGAs) of Edo State, Nigeria, and evaluated the potential health risks to children. The results revealed that concentrations of Fe, Ni, Cr, Cu, Zn, Mn, and Pb were generally low, while Cd was below detection limits. The overall values were below the threshold limits set by WHO, FEPA, and EU standards, and the computed pollution indices (CF, Cdeg, PLI, and Igeo) indicated that the playground soils were practically uncontaminated. Health risk assessment further showed that the hazard quotients (HQ) and hazard indices (HI) for all exposure pathways were less than 1, suggesting no immediate non-carcinogenic risks to children. However, the presence of Pb, though minimal, is of concern because of its well-documented neurotoxic effects, especially in children. Moreover, variations in heavy metal concentrations across the LGAs highlight the influence of both natural (lithogenic) and localized anthropogenic sources such as traffic emissions, waste disposal and playground infrastructure. While the current contamination levels do not pose significant risks, the potential for bioaccumulation and long-term exposure cannot be overlooked, particularly as Edo State continues to experience rapid urbanization, population growth, and increased vehicular activities.

Therefore, this study underscores the importance of regular environmental monitoring of school playground soils to provide early warnings of possible contamination. Preventive measures such as the maintenance of playground facilities, enforcement of waste management regulations, restriction of open burning around schools, and awareness campaigns on children's hygiene practices (e.g., handwashing after play) are strongly recommended. Furthermore, the findings serve as valuable baseline data for policymakers and researchers, and should stimulate broader investigations covering more LGAs in Edo State and other regions of Nigeria. Continuous surveillance and proactive interventions are essential to safeguard children; one of the most vulnerable groups in society from the potential hazards of heavy metal exposure.

Conflicts of Interest

All authors have no conflicts of interest to declare.

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References

- Acosta, J. A., Cano, A. F., Arocena, J. M., Debela, F., & Martínez-Martínez, S. (2009). Distribution of metals in soil particle size fractions and its implication to risk assessment of playgrounds in Murcia City (Spain). *Geoderma*, 149(1-2), 101-109. DOI: <https://doi.org/10.1016/j.geoderma.2008.11.034>
- Adebamowo, E. O., Agbede, O. A., Sridhar, M. K., & Adebamowo, C. A. (2006). An examination of knowledge, attitudes and practices related to lead exposure in South Western Nigeria. *BMC Public Health*, 6(1), 82. <https://doi.org/10.1186/1471-2458-6-82>
- Adimalla, N., & Wang, H. (2018). Distribution, contamination, and health risk assessment of heavy metals in surface soils from northern Telangana, India. *Arabian Journal of Geosciences*, 11(21), 1 - 15. DOI: <https://doi.org/10.1007/s12517-018-4028-y>
- Biose, E., Amaechi, C. F., & Nwaemene, C. (2021). Heavy Metal Contents in Topsoil of Selected Public Primary Schools Playground in Benin Metropolis, Nigeria. *J. Appl. Sci. Env. Manage.* 25(2): 173 - 182. DOI: [10.4314/jasem.v25i2.6](https://doi.org/10.4314/jasem.v25i2.6)
- De-Mingeul, E., Iribarren, I., Chacon, E., Ordonez, A., & Charlesworth, S. (2007). Risk-based evaluation of the exposure of children to trace elements in playgrounds in Madrid. *Chemosphere*, 66, 505 - 513. <https://doi.org/10.1016/j.chemosphere.2006.05.065>.
- Doku, E. T., Adjei-Hinne, G., & Justice, A. (2023). Playground Soil Contamination with Heavy Metals and Associated Health Risks of Children in Schools Located in the Sunyani-East Municipality of Ghana. *EnvironmentAsia*, 16(1), 73 – 86. DOI: <https://doi.org/10.14456/ea.2023.7>
- Donado, E. P., Oliveira, M. L., Gonçalves, J. O., Dotto, G. L., & Silva, L. F. (2021). Soil contamination in Colombian playgrounds: effects of vehicles, construction, and traffic. *Environmental Science and Pollution Research*, 28(1), 166-176. <https://doi.org/10.1007/s11356-020-09965-w>
- Durowoju, O. S., Edokpayi, J. N., Popoola, O. E., & Odiyo, J. O. (2018). Health risk assessment of heavy metals on primary school learners from dust and soil within school premises in Lagos State, Nigeria. In *Heavy metals*. IntechOpen. DOI: <https://doi.org/10.5772/intechopen.74741>.
- European Environmental Agency (EEA) (2003). *Europe's environment: the third assessment*, Annual report. Luxembourg, 52pp.
- Guo, B., Su, Y., Pei, L., Wang, X., Wei, X., Zhang, B., Zhang, D., & Wang, X. (2020). Contamination, Distribution and Health Risk Assessment of Risk Elements in Topsoil for Amusement Parks in Xi'an, China. *Polish Journal of Environmental Studies*, 30(1), 601 - 617. DOI: <https://doi.org/10.15244/pjoes/123606>
- Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research*, 14(8), 975–1001. [https://doi.org/10.1016/0043-1354\(80\)90143-8](https://doi.org/10.1016/0043-1354(80)90143-8)
- Jafari, A., Ghaderpoori, M., Kamarehi, B., & Abdipour, H. (2019). Soil pollution evaluation and health risk assessment of heavy metals around Douroud cement factory, Iran. *Environmental Earth Sciences*, 78, 250-263. DOI: <https://doi.org/10.1007/s12665-019-8220-5>
- Javed, S. A., Al-Bratty, M., Al-Rajab, A. J., Alhazmi, H. A., Ahsan, W., Abdelwahab, S. I., & Thangavel, N. (2019). Risk-based exposure assessment for multiple toxic elements encountered by children in school playgrounds and parks in the southwest region of Saudi Arabia. *Environmental Monitoring and Assessment*, 191(9), 1 - 16. DOI: <https://doi.org/10.1007/s10661-019-7640-8>
- Jonathan, M. P., Ram-Mohan, V., & Srinivasalu, S. (2004). Geo-chemical variation of major and trace elements in recent sediments of the Gulf of Mannar the southeast coast of India, *Environmental Geology*, 45(4), 466 - 480. DOI: <https://doi.org/10.1007/s00254-003-0898-7>
- Kanu, M. O., Meludu, O. C., & Oniku, S. A. (2015). Evaluation of Heavy Metal Contents in Road Dust of Jalingo, Taraba State, Nigeria. *Jordan Journal of Earth and Environmental Science*, 7(1), 65-70
- Kyene, M. O., Gbeddy, G., Mensah, T., Acheampong, C., Kumi-Amoah, G., Ketemepi, H. K., & Darko, D. A. (2023). Bioaccessibility and children health risk assessment of soil-laden heavy metals from school

- playground and public parks in Accra, Ghana. *Environmental Monitoring and Assessment*, 195(10), 1199 - 11203. DOI: <https://doi.org/10.1007/s10661-023-11818-1>
- Likuku, A. S., Mmolawa, K. B., & Gaboutloeloe, G. K. (2013). Assessment of heavy metal enrichment and degree of contamination around the copper-nickel mine in the Selebi Phikwe Region, Eastern Botswana. *Environment and Ecology Research*, 1(2), 15 - 17.
- Muller, G (1979). Index of geo-accumulation in sediments of the Rhine River. *Geojournal*, 2(3), 108-118. <https://sid.ir/paper/618491/en>.
- Nduka, J. K., Umeh, T. C., Kelle, H. I., Okeke, F. C., Iloka, G. C., & Okafor, P. C. (2024). Ecological pollution features and health risk exposure to heavy metals via street dust and topsoil from Nkpor and Onitsha in Anambra, Nigeria. *Environmental Analysis, Health and Toxicology*, 39, e2024005. DOI: [10.5620/eaht.2024005](https://doi.org/10.5620/eaht.2024005)
- Okereke, C. J., & Amadi, P. U. (2017). Accumulation and risk assessment of heavy metal contents in school playgrounds in Port Harcourt Metropolis, Rivers State, Nigeria. *Journal of Chemical Health & Safety*, 24(5), 11-22. DOI: <https://doi.org/10.1016/j.jchas.2017.01.0>
- Okereke, C. J., Nnabugwu, A. E., & Amadi, P. U. (2017). Accumulation and toxicological risk assessment of Cd, As, Pb, Hg and Cu from topsoils of school playgrounds at Obio-Akpor LGA, Rivers State, Nigeria. *International Journal of Scientific World*, 5(1), 38 - 46. DOI: <https://10.14419/ijsw.v5i1.6710>
- Parlak, M., Tunçay, T., & Botsou, F. (2022). Heavy metals in soil and sand from playgrounds of Çanakkale city (Turkey), and related health risks for children. *Sustainability* 14, 1145. <https://doi.org/10.3390/su14031145>.
- Penteado, J. O., De-Lima, B. R., Ramires, P. F., Garcia, E. M., Dos-Santos, M., & Da-Silva Júnior, F. M. R. (2021). Health risk assessment in urban parks soils contaminated by metals, Rio Grande city (Brazil) case study. *Ecotoxicology and Environmental Safety*, 208, 111737. <https://doi.org/10.1016/j.ecoenv.2020.111737>
- Popoola, O. E., Bamgbose, O., Okonkwo, O. J., Odukoya, T. A., & Popoola, A. O. (2012). Heavy Metals Content in Playground Topsoil of Some Public Primary Schools in Metropolitan Lagos, Nigeria, *Research Journal of Environmental and Earth Sciences* 4(4), 434-439. DOI: <https://www.airitilibrary.com/Article/Detail?DocID=20410492-201204-201507220026-201507220026-434-439>
- Tepanosyan, G., Maghakyan, N., Sahakyan, L., & Saghatelian, A. (2017). Heavy metals pollution levels and children health risk assessment of Yerevan kindergartens soils. *Ecotoxicology and environmental safety*, 142, 257 – 265. <https://doi.org/10.1016/j.ecoenv.2017.04.013>
- United States Environmental Protection Agency, (USEPA). (2005). Guidelines for carcinogen risk assessment. Risk Assessment Forum, Washington, DC (EPA/630/P-03/001F).
- Verla, A. W., & Verla, E. N. (2017). Risk associated with heavy metals in children playground soils of Owerri Metropolis, Imo state, Nigeria. *World News of Natural Sciences*, 10, 49 - 69. DOI: <https://bwmeta1.element.agro-7fc2f5e7-aeaf-4518-9a17-cc63aa1d129d>.
- Verla, E. N., Verla, A. W., & Ugwulor, L. (2015). Seasonal variation of heavy metals in playgrounds of public schools within Owerri Metropolis, Imo State, Nigeria. *International Letters of Chemistry, Physics and Astronomy*, 50, 61-70. d DOI: <https://10.18052/www.scipress.com/ILCPA.50.61>.
- Wang, S., Wu, W., & Liu, F. (2019). Assessment of the human health risks of heavy metals in nine typical areas. *Environmental Science and Pollution Research*, 26(12), 12311-12323. DOI: <https://doi.org/10.1007/s11356-018-04076-z>.
- Yahaya, T. O., Oladele, E. O., Chibs, B., Abdulazeez, A., Nnochiri, K., Stephen, A. O., Ahmed, H., & Daniel, A. (2020). Level and health risk evaluation of heavy metals and microorganisms in urban soils of Lagos, Southwest Nigeria. *Algerian Journal of Biosciences*, 1(2), 51 - 60. DOI: <https://journal.acse.science/index.php/ajb/article/view/82>.

Zgłobicki, W., Telecka, M., & Skupiński, S. (2021). Heavy metals in playgrounds in Lublin (E Poland): sources, pollution levels and health risk. *Environmental Science and Pollution Research*, 28(15), 18328-18341. DOI: <https://doi.org/10.1007/s11356-020-09375-y>