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Pollution indices and health risk evaluation of heavy metals in a playground soil from Katsina state, Northwestern Nigeria.

Índices de contaminación y evaluación de riesgos para la salud de metales pesados en el suelo de un patio de recreo del estado de Katsina, noroeste de Nigeria.

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ABSTRACT

The pollution indices and health risks to the population from exposure to heavy metals in a playground soil sample was carried out in the current study. The soil sample heavy metal concentrations were determined using Atomic Absorption Spectrophotometry. The heavy metals soil pollution indices were computed based on the Geoaccumulation index (Igeo), enrichment factor (EF), contamination factor (CF), pollution load index (PLI) and potential ecological risk index (PERI). The health risks of the evaluated heavy metals to the population were calculated using the Hazard Quotient (HQ) and Hazard Index (HI)) to assess the possible non-carcinogenic effect and the Incremental Lifetime Cancer Risk (ILCR) for the cancer risks. The results had revealed that all the evaluated heavy metals were within the regulatory bodies' permissible limits. The I-geo values have revealed that the soil sample was unpolluted with these heavy metals. In addition, the heavy metal enrichment factor (EF) shows a varying degree of enrichment; Fe and Mn (deficiency to minimal) Zn (Moderate), Ni (significant), Cr (extremely high). The result of the contamination factor has indicated that the soil sample in the study has low contamination by the heavy metals. The result of pollution load index was less than 1. With the potential ecological risk index (PERI) values presenting low ecological risks. The calculated non-cancer risk indices in both the children and adult population for the heavy metals were below 1. The Incremental Life Cancer Risk (ILCR) for both the adult and children population has revealed that the heavy metal Ni was beyond the threshold of the safety range for cancer risk. The results of the pollution indices have indicated that the soil sample have low contamination, while the results for the health risk evaluation pointed to the possible contribution of exposure to the soil sample to heighten the risks for cancer in the population.

Keywords: Soil, Environment, Heavy metals, Katsina, Nigeria, Cancer, Health, Children

RESUMEN

En el presente estudio se llevaron a cabo los índices de contaminación y los riesgos para la salud de la población por la exposición a metales pesados en una muestra de suelo de un patio de juegos. Las concentraciones de metales pesados de la muestra de suelo se determinaron mediante espectrofotometría de absorción atómica. Los índices de contaminación del suelo por metales pesados se calcularon con base en el índice de geoacumulación (Igeo), el factor de enriquecimiento (EF), el factor de contaminación (CF), el índice de carga contaminante (PLI) y el índice de riesgo ecológico potencial (PERI). Los riesgos para la salud de los metales pesados evaluados para la población se calcularon utilizando el Cociente de Riesgo (HQ) y el Índice de Riesgo (HI) para evaluar el posible efecto no cancerígeno y el Riesgo Incremental de Cáncer de por Vida (ILCR) para los riesgos de cáncer. Los resultados revelaron que todos los metales pesados evaluados se encontraban dentro de los límites permitidos por los organismos reguladores. Los valores de I-geo han revelado que la muestra de suelo no estaba contaminada con estos metales pesados. Además, el factor de enriquecimiento (EF) de metales pesados muestra un grado variable de enriquecimiento; Fe y Mn (deficiencia mínima), Zn (moderada), Ni (significativa), Cr (extremadamente alta). El resultado del factor de contaminación ha indicado que la muestra de suelo en estudio tiene baja contaminación por metales pesados. El resultado del índice de carga contaminante fue inferior a 1. Los valores del índice de riesgo ecológico potencial (PERI) presentan riesgos ecológicos bajos. Los índices de riesgo no cancerígeno calculados tanto en la población infantil como en la adulta para los metales pesados estaban por debajo de 1. El riesgo incremental de cáncer de vida (ILCR) tanto para la población adulta como para la infantil ha revelado que el metal pesado Ni estaba más allá del umbral del rango de seguridad para el riesgo de cáncer. Los resultados de los índices de contaminación indicaron que la muestra de suelo tiene baja contaminación, mientras que los resultados de la evaluación de riesgos para la salud señalaron la posible contribución de la exposición de la muestra de suelo a aumentar los riesgos de cáncer en la población.

Palabras clave: Suelo, Medio ambiente, Metales pesados, Katsina, Nigeria, Cáncer, Salud, Niños

INTRODUCTION

One of the biggest problems to environmental and human health is the steadily growing concentrations of heavy metals in the environment (Wojciech *et al*., 2021). Heavy metals being toxic at trace levels and coupled with their being persistent and ubiquitous, their presence in the environment is raising much attention (Jia *et al*., 2018; Ali *et al*., 2019).

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 metal concentrations above regulatory limits in soils may lead to an increased risk of chronic degenerative diseases (Yaradua *et al*., 2022). Furthermore, heavy metals risk quantification is of uttermost importance for children's playground since these metals accumulate with time and the awareness regarding playgrounds safety especially in Nigeria is still low (Wirnkor and Ngozi, 2017).

Studies have been carried out on the heavy metal contamination, identification of source, distribution pattern, degree of pollution, and associated human health risks in many parts of the world and in Katsina State, Nigeria (Mihaileanu *et al*., 2019; Gebeyehu and Bayissa 2020; Yaradua *et al.*, 2020; Wojciech *et al*., 2021; Yaradua *et al*., 2022). But few studies were carried out on the risk assessment of playground soils in Nigeria (Popoola *et al*., 2012; Wirnkor and Ngozi, 2017; Evelyn *et al*., 2018; Biose *et al*., 2021), and to date, none has been carried out in Katsina State, Nigeria. This has led to the absence of information on the possible health risks from heavy metals exposure associated with playgrounds from Katsina State, Nigeria.

The chosen site for the study (Garama primary school), is located in Katsina metropolis, in an area with multiple potential sources of heavy metal pollution. Located close to the school is a motor cycle repair workshop, a market that deal in imported fairly used electronic appliances, a motor park, various metal artisanal workshops and the community refuse dump. Therefore, the present investigation was tailored to explore (i) the degree of heavy metals contamination in the playground soil sample (ii) to determine the contamination status of the evaluated heavy metals using different pollution indices (iii) to assess the public health risks (non-carcinogenic and carcinogenic) associated with heavy metals exposure from the playground soil. The information from the study is geared towards enriching the expanding data on heavy metal health risks in environmental samples to the population from Katsina State, Nigeria (Yaradua *et al.*, 2018a; Yaradua *et al*., 2018b; Yaradua *et al*., 2020; Yaradua *et al*., 2021; Yaradua *et al*., 2022).

MATERIAL AND METHODS

Study area: Garama Primary School is located behind Kandahar Juma'at mosque in Katsina metropolis at a latitude of 12.9' 43°N and longitude of 7.6' 42°E. The school was established in the late 1960s, by the then Katsina native authority (NA) administration. The playground of the primary school (which is located within the school premises), was selected as the study area. Various games are played within the school playground, such as Football, Volleyball, Table Tennis, Racing, etc.

Soil sampling: Soil sample from Garama primary school Playground was collected from three different locations. All heavy particles such as stones, small stick and other large debris were removed. The soil samples were then sieved through a 2 mm sieve and stored in labeled polythene sampling bags (Lei *et al*., 2008).

Digestion and heavy metal analysis: Exactly 1 g of soil sample was digested by 15 ml di acid mixture i.e. HNO_3, HCl, and H_2O_2 as catalyst at a ratio of 3:1:1 and at a temperature of 100°C until a transparent solution appeared. [USEPA Method: 3005A] (USEPA, 2011). The volume of the digest was adjusted to 50 ml by adding distilled water. The concentrations of the heavy metals were determined using a flame atomic absorption spectrophotometer (Varian FAAS-240).

ASSESSMENT OF SOIL SAMPLES CONTAMINATION STATUS

The heavy metal contamination status of the soil sample was evaluated using the Geoaccumulation index (Igeo), enrichment factor (EF), contamination factor (CF), degree of contamination (DC), pollution load index (PLI) and potential ecological risk index (PERI). The geo accumulation index, Igeo serve as an indication of the enrichment of metals above the background concentrations, where:

$I\text{-geo} = \log_2 / (C_n / 1.5B_n)$ ……………………eqn. (1)

The soil sample is classified as unpolluted if the Igeo value < 0. With progressive contamination in the sample shown as an increase in Igeo value ($0 < I\text{geo} < 1$), ($1 < I\text{geo} < 2$), ($2 < I\text{geo} < 3$), and ($3 < I\text{geo} < 4$) pointing to the soil sample as being unpolluted, moderately polluted, and heavily polluted, respectively (Müller, 1969).

The enrichment factor (EF) is a presentation of the abundance of the heavy metals in the soil sample when compared to the concentration of a reference metal (Müller, 1981), and is given below:

$EF = (M/Fe)_{sample} / (M/Fe)_{Background}$ …………………eqn. (2)

With EF being the enrichment factor, (M/Fe) sample being the ratio of metal and the Fe concentration of the sample and (M/Fe) background is the ratio of metals and the background concentration of the heavy metal Fe. The EF is grouped into five categories (Sutherland, 2000). EF <2 deficiency to minimal enrichment, EF = 2-5 moderate enrichment, EF = 5-20 significant enrichment, EF = 20-40 very high enrichment, EF>40 extremely high enrichment. The contamination factor (CF) is the concentration of a given element, C_{sample}, against the average world background concentration of the metal, $C_{background}$. When the CF value is < 1, it indicates a low degree of contamination.

The pollution load index (PLI) is calculated as follows:

$= (CF_1 \times CF_2 \times CF_3 \times \cdots CF_n)\ 1/\ldots$, eqn. (3)

With n being the number of metals, a PLI value of >1 is a suggestion that the soil is polluted, while a PLI < 0 is an indication that the soil is unpolluted by the heavy metals. To calculate the PERI for each individual metal, the following equation was used;

Eri = Tri x Cfi …………. eqn. (4)

With Tri as the toxicity coefficient of each metal, whose standard values are taken as; Cd = 30, Ni = 5, Pb = 5, Cr = 2, and Zn = 1, Mn = 1 (Hakanson, 1980; Xu *et al*., 2006), while Cfi is the contamination factor. The following order was used to describe the ecological risk index: Er < 40, low; 40 ≤ Er < 80, moderate; 80 ≤ Er < 160, considerable; 160 ≤ Er < 320, high; and Er ≥ 320, very high.

HEALTH RISK ASSESSMENT (HRA)

The United States environmental protection agency (USEPA) models (2014) for risk assessment (Hazard Quotient (HQ) and Hazard Index (HI)) were employed to evaluate the possible non-carcinogenic health risk in the children and adult population from exposure to the study heavy metals. In the current study two exposure routes were used (Dermal and inhalation).

Dermal route (Der): The Hazard Quotient (HQ) from exposure to the heavy metals in the study through dermal contact were evaluated using the below equation

(CM x SA x SAF x DAF x EF x ED) / (BW x AT x RFD) .... eqn. (5)

The Hazard Index (HI) was evaluated using the below equation

HI = ∑HQ ……………………………… eqn. (6)

Inhalation route (Inh): The Hazard Quotient (HQ) from exposure to the heavy metals in the study through inhalation were evaluated using the below equation

(CM x InhR x EF x ED) / (BW x AT x RFD x PET) …………. eqn. (6)

The Hazard Index (HI) was evaluated using the below equation

HI = ∑HQ …………. eqn. (7)

HQ is the hazard quotient due to heavy metals in soil. CM is the concentration of heavy metal; EF is the exposure frequency in days/year (360, child; 360, adult). ED is the exposure duration in years (6, child; 70, adult). BW is the body weight in kg (15, child; 70, adult). AT is the average time in days (2190, child; 25550, adult). RFD is the reference dose of heavy metals. SA is the skin surface area in cm^2 (2800, child; 17500, adult). SAF is the soil adherence factor in mg/cm^3 (0.2, child; 0.07, adult). DAF is the dermal absorption factor unit less (0.001, child; 0.001, adult). InhR is the inhalation rate in m^3/day (8.6, child; 15.2, adult). IngR is the ingestion rate in mg/day (200, child; 100, adult). PEF is the particulate emission factor in m^3/kg (1.32×10^9, child; 6.79×10^8, adult). HQ is the hazard quotient due to heavy metal. HI > 1 indicates a potential for adverse effect (Olagunju *et al*., 2020).

Chart 2: Reference Doses (RFD) (mg/kg/day) of Heavy Metals via Dermal and Inhalation Exposure Routes Used for the Non-Carcinogenic Health Risk Assessment.

Heavy metals	Pb	Cd	Cr	Ni	Mn	Fe	Zn
RFD Dermal	5.3 E -4	1.0 E -3	3.0 E -3	2.0 E -2	1.8 E -3	7.0 E -1	3.0 E -1
RFD Inhalation	3.5 E -3	5.7 E -5	3.0 E -5	2.5 E -2	1.4 E -5	8.0 E -1	3.5 E -1

Cancer risks from exposure to the soil samples: The possibility of cancer risks in the studied samples through exposure to carcinogenic heavy metals were estimated using the Incremental Lifetime Cancer Risk (ILCR) (Liu *et al*., 2013).

ILCR= CDI×CSF ………………eqn. (8)

Where, CDI is chronic daily intake of chemical carcinogen, mg/kg BW/day which represents the lifetime average daily dose of exposure to the chemical carcinogen.

The ILCR was evaluated by the use of the cancer slope factor (CSF), which is the representative risk incurred through a lifelong average dose of 1 mg/kg BW/day and is heavy metal specific (Micheal *et al*., 2015). The following cancer slope factor for specific heavy metals were used; Pb = 0.0085 mg/kg/day (Kamunda *et al*., 2016), Cd = 0.38 mg/kg/day (Yang *et al*., 2018), Cr = 0.5 mg/kg/day (Javed and Usmani, 2016). The ILCR valuation result in the sample give a picture of the possibility of an individual's lifetime cancer risks from exposure to the carcinogenic heavy metals' in the sample under study (Pepper *et al*., 2012). The standard of acceptability for cancer risk (ILCR) as set by the regulatory bodies was considered within the range of 10^{-6} to 10^{-4} (Li and Zhang, 2010).

The cumulative cancer risks in the samples, because of multiple exposures to the metallic carcinogens in the soil samples was taken to be the sum of the individual heavy metal increment risks, and is calculated by the following equation (Liu *et al*., 2013).
$\sum 1n = ILCR1 + ILCR2 + \cdots + ILCRn$……………………. eqn. (9)

Where, n = 1, 2 …, n is the individual carcinogenic heavy metal.

RESULTS AND DICUSSION

Heavy metal concentrations in soil sample: The result of the mean concentration values of the evaluated heavy metals from the playground soil sample as displayed in Table 1 lies within the Maximum Allowable Concentrations (MAC) of heavy metals in soil (FAO/WHO, 2011). The order of the sequence of the mean metal concentrations is as follows Fe>Cr>Mn>Zn>Ni. In addition, the mean values of evaluated metals were lower than the reported mean values of Heavy metals in a playground soil sample from Lublin, Poland (Wojciech *et al*., 2021). The Apparent lower values obtained may not be unconnected with the individual setting of the compared literature, as areas close to heavy individual sites are more readily polluted compared to the sampling site in the current study. However, the mean values were higher when compared to previously reported values obtained for heavy metals in soil samples from Katsina state Nigeria (Yaradua *et al*., 2020; Yaradua *et al*., 2022). An observation that can be attributed to the multiple metal contamination sites that are in close proximity to the study site.

Table 1 Mean Heavy Metal Concentrations (ppm) in Soil Sample from Garama Primary School Playground, Katsina.

Heavy Metal	Mean Concentration
Fe	4.743 ± 0.1492
Cr	0.496 ± 0.0514
Mn	0.114 ± 0.0040
Zn	0.056 ± 0.0047
Ni	0.015 ± 0.0058
Pb	BDL
Cd	BDL
Cu	BDL

Key: BDL= below detection level.

HEAVY METALS SOIL POLLUTION INDICES

Geoaccumulation index: The Result of the I-geo values of the evaluated heavy metals was all below 1 which indicates that the soil sample is unpolluted with these heavy metals (Table 2). The values were similar to the I-geo values reported for soil samples in studies that were previously conducted in Katsina State, Nigeria (Yaradua *et al*., 2020; Yaradua *et al*., 2022). In addition, the I-geo values of the evaluated metals were lower than the reported I-geo values in playground soil samples from Khagra West Bengal, India (Tanmay *et al*., 2016) and from primary schools playground soils in Benin Metropolis, Nigeria (Biose *et a., 2021l*).

Enrichment factor (EF): The Result of the heavy metals EF in this study (Table 2) shows a varying degree of enrichment by the metals; Fe and Mn (deficiency to minimal) Zn (Moderate), Ni (significant), Cr (extremely high). The EF values for the evaluated heavy metals Fe and Mn are in line with the findings of the playgrounds soil samples from Khagra, India (Tanmay *et al*., 2016). The EF of Ni and Cr in the present study are also similar to the values reported for some public primary school playgrounds from Benin City, Nigeria (Biose *et al., 2021*). In addition, the high metal enrichment values observed for the heavy metals Ni and Cr is an indication of their anthropogenic origin. This may not be unconnected with the close proximity of the playground to a fairly used electronics market that may potentially emanates e-waste, which has been implicated as a contributor of Ni and Cr to the environment in an earlier study (Zeng *et al*., 2016).

Contamination factor (CF): The heavy metal contamination of soils is usually a pointer of the role played by anthropogenic sources to the metal build up. The result of the contamination factor for all the calculated values in the present study were below 1 (Table 2), an indication that the soil sample in the study has low contamination by the heavy metals. The Contamination Factor reported from Khagra West Bengali playground, India also shows low to moderate contamination for the evaluated heavy metals (Tanmay *et al*., 2016) which is in line with the findings of this study. But the result was in contrast to the values reported from studies conducted in various play grounds from Nigeria that shows moderate, considerable and high contamination for the heavy metals that were investigated, observations that might be attributed to the anthropogenic sources that normally occur in soil through human activities (Wojciech *et al*., 2021; Nwaogu *et al*., 2014).

Degree of contamination (DC): The result of degree of contamination of the present study for soil sample is less than 6 as displayed in Table 2, an indication of the low degree of contamination. A finding, that was similar to previously reported heavy metals degree of contamination for soil samples from Katsina State, Nigeria (Yaradua *et al*., 2020; Yaradua *et al*., 2022).

Pollution load index (PLI): The result of pollution load index of the present study for playground soil sample obtained was less than 1 (Table 2), an indication that the soil sample is unpolluted with these heavy metals. The result is in contrast with the values of PLI Reported from selected public primary school playgrounds in Benin city that were greater than 1 (PLI>1) (Biose *et al., 2021*).

Potential ecological risk index (PERI): The result of PERI of soil from the current study (Table 2) for all the heavy metals obtained shows low ecological risk index, which is an indication of non-pollution to the soil from the evaluated heavy metals. A result that was similar with the PERI values from a playground in Lublin, Poland (Wojciech *et al*., 2021).

Table 2 Heavy Metals Pollution Indices of Soil Sample from Garama Primary school Play Ground Katsina, Katsina State.

Heavy Metal	IGEO	EF	CF	PERI
Fe	2.651E-05	1.000	1.321E-04	1.321E-04
Pb	BDL	BDL	BDL	BDL
Cu	BDL	BDL	BDL	BDL
Zn	1.182E-04	4.538	5.894E-04	5.894E-04
Ni	3.459E-04	13.166	1.724E-03	8.600E-03
Cd	BDL	BDL	BDL	BDL
Cr	1.233E-03	47.727	6.146E-03	1.228E-02
Mn	3.050E-05	1.143	1.520E-04	1.520E-04
DC	0.008564			
PLI	8.564			

Key: IGEO= Geo-accumulation, EF= Enrichment Factor, CF= Contamination Factor, PERI= Potential Ecological Risk Index, DC= Degree of contamination, PLI= Pollution Load Index, BDL= Below Detection Level.

HEAVY METALS HEALTH RISK INDICES

Non-cancer risks: The result of the Target Hazard Quotient (THQ) and Health Risk Index (HRI) associated with the evaluated heavy metals exposure through inhalation or dermal contact in the study area for adult and children of the evaluated heavy metals were below 1 (Tables 3 and 5). This is a pointer that the heavy metals may not pose a health risk (non-carcinogenic) to the population living in the area.

Table 3 Target Hazard Quotient (THQ) and Health Risk Indices (HRI) in Children Associated with Inhalation and Dermal Heavy Metal Exposure in Soil Sample from Garama primary school playground, Katsina Metropolis.

HEAVY METAL	THQ	
	INHALATION	DERMAL
Mn	3.4884E03	6.4779E03
Zn	6.8543E-08	4.4060E-05
Cu	BDL	BDL
Ni	2.5704E-08	7.6712E-06
Fe	2.5398E-09	6.9304E-04
Cd	BDL	BDL
Pb	BDL	BDL
Cr	7.0827E06	1.6911E03
HRI	3.4956E03	8.9138E-03

Table 4 Target Hazard Quotient (THQ) and Health Risk Indices (HRI) in Adults Associated with Inhalation and Dermal Heavy Metal Exposure in Soil Sample from Garama primary school playground, Katsina Metropolis.

HEAVY METAL	THQ	
	INHALATION	DERMAL
Mn	2.5684E03	3.0365E04
Zn	5.0467-08	2.0653E-06
Cu	BDL	BDL
Ni	1.8925E-09	3.5959E-06
Fe	1.8700E-09	3.2486E-05
Cd	BDL	BDL
Pb	BDL	BDL
Cr	5.2149E06	7.9269E04
HRI	2.5737E-03	1.1345E-03

Key: BDL= below detection level; THQ= Target Hazard Quotient; HRI = Health Risk index

Cancer risks: The Result of the Incremental Life Cancer Risk (ILCR) for both the adult and children population as represented in Table 5 shows that the heavy metal Ni is beyond the threshold of the safety range for cancer risk. This is an indication that, it can pose a threat of cancer risk to the population living in the area. The apparent higher value obtained for Ni in the present study compared to earlier report (Yaradua *et al*., 2022), may be due to anthropogenic sources, like the dumps of damaged phones, computers and batteries that are very close to the playground. The result also differ with the reported ∑ILCR for Ni ($<10^{-6}$) in playground soil sample from Lublin, Poland (Wojciech *et al.*, 2020).

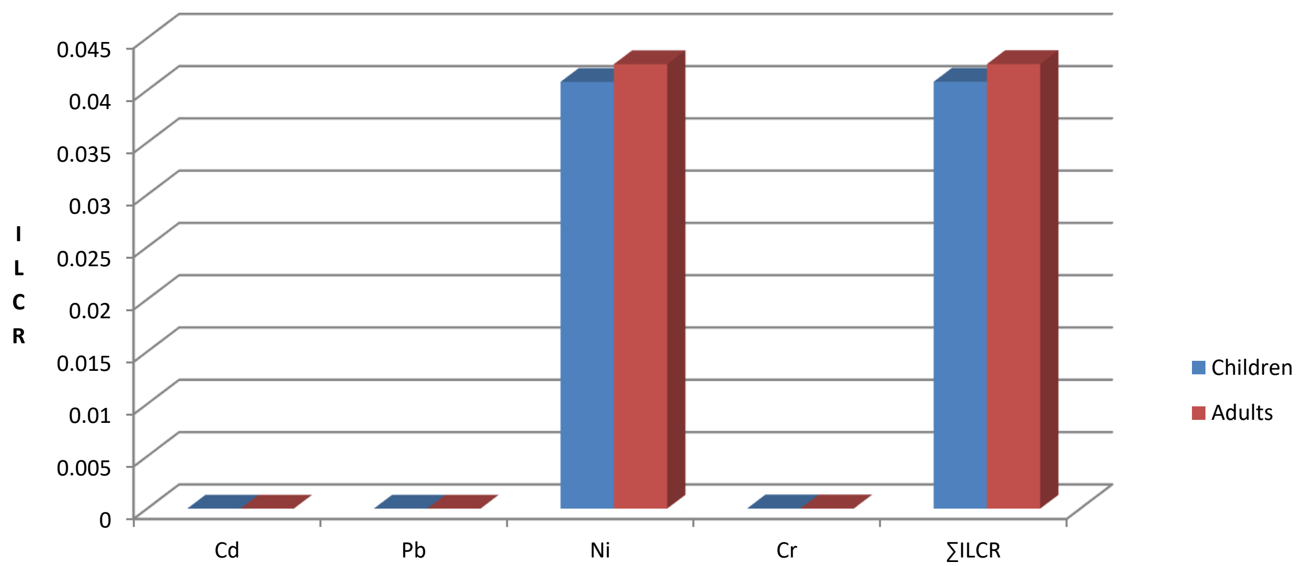

Fig. 1 Cancer Risks in the Children and Adult Population Associated with Heavy Metal Exposure from Garama primary school playground, Katsina , Katsina State, Nigeria.

Key: ILCR= Incremental Lifetime Cancer Risk; ∑ILCR= Cumulative Incremental Lifetime Cancer Risk.

CONCLUSION

This study evaluated pollution indices and health risks to the population from exposure to heavy metals in an urban playground soil sample. The metal concentrations in the playground soil studied, were within the regulatory agencies permissible limits. With the exception of the result of the heavy metal EF of the soil sample that showed varying degree of enrichment, all the other pollution indices have values that fall within the safety limit for soil. From the results, both the calculated THQ and HRI through inhalation and dermal contact for the evaluated heavy metals were below 1, pointing to a low non-cancer risk to the population. The ILCR for Ni was above the threshold of the safety range for cancer risk in the children and adult population, heightening the cancer risks from the evaluated metals in the population of the study area.

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