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Assessment of Heavy Metals Concentration in Soil and Plants from Oil-Producing Area of Delta State, Nigeria

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Abstract: In this study, the heavy metal concentration in soil and plants from the oil-producing area (Delta State) of Nigeria was investigated. A total of thirty (30) soil and plant samples were collected from farms in Sapele, Delta State. These samples were collected randomly from each sampling farms around the oil exploration sites. The samples were analyzed for heavy metal concentration levels in the samples using an X-ray fluorescence spectrometer. The soil to plant transfer factor, carcinogenic, and non-carcinogenic risk assessment were determined. The mean concentration of heavy metals in soil (plant) are 0.005197933 mg/kg (0.001025 mg/kg), 0.005183467 mg/kg (0.0014 mg/kg), 0.004088067 mg/kg (0.001541 mg/kg), 0.012421133 mg/kg (0.002491 mg/kg) and 0.001799733 mg/kg (0.000539 mg/kg) for Cr, Pb, Ni, Zn, and Cu, respectively. The mean transfer factor of Cr, Pb, Ni, Zn, and Cu is 0.12983366, 0.34. The mean ADI for ingestion in Child (Adult) are 7.845E-09 (3.05162E-09), 7.8241E-09 (3.04313E-09), 6.17067E-09 (2.40004E-09), 1.87489E-08 (7.29225E-09), 2.71658E-09 (1.05659E-09), and 4.33E-08 (1.68E-08), respectively. 2885048, 0.411881704, 0.163634563, and 0.324159195, respectively. The mean HQ for ingestion in Child (Adult) are 2.61531E-06 (1.01721E-06), 2.23546E-06 (8.69466E-07), 3.08533E-07 (1.20002E-07), 6.24963E-08 (2.43075E-08), and 2.43075E-08 (2.64149E-08), respectively. The calculated ADI values for all metals, across all exposure pathways, are several orders of magnitude below the WHO-recommended limits. This suggests that the current levels of heavy metals in the study area pose minimal risk to both children and adults.

Keywords: Heavy metals, carcinogenic and non-carcinogenic risk, hazard indices, and X-ray fluorescence spectrometer.

1 Introduction

The environment is progressively being altered in recent times through the activities of man and his technological advancement [1, 5]. The role of heavy metals in the environmental matrices is increasingly becoming an issue of global concern to farmers, policymakers, and researchers [6-9]. Heavy metals have become a widespread problem around the world in recent years. However, heavy metals are found ubiquitously in both polluted and unpolluted environments [10-13]. The level of heavy metals in the environment varies between different regions, resulting in spatial variations in their concentration. Although heavy metals occur naturally in the earth's crust, they tend to be concentrated in agricultural soils because of the application of commercial fertilizers, manures, and sewage sludge [14-16].

Despite the essential role played by food in supporting human life, it also has great potential for transmitting a wide variety of diseases and illnesses [17-21]. Due to rapid population growth, urbanization, industrialization, and the exploitation of natural resources, there has been a steady increase in the quantity, quality, and diversity of discharges into the aquatic environment. These discharges contain a huge amount of heavy metals, which adversely affect the physicochemical properties of the receiving water and consequently its biota [22-24]. Heavy metals can induce adverse effects on humans and wildlife even at trace levels. Soil serves as a basic component of our environment, provides foodstuffs for organisms, and also serves as a sink and reservoir for a variety of contaminants [25-29]. In order to protect both health and the environment. It is necessary to regulate the amount of these harmful pollutants that are released

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without causing unacceptable harm to health and the environment. Regulation in this way involves setting control standards on the potentially harmful pollutants that can be released into the environment [30-32].

2 Methods

2.1 Study Area

The study area of this study is Sapele, Delta State, Nigeria. It lies on the coordinates 5.5766° N and 5.9094° E. This place is characterized by its sedimentary formations, which have been shaped by the Niger River and other smaller rivers in the region. These rivers have deposited large amounts of sediment over millions of years, resulting in the formation of various geological features such as sandstones, shales, and conglomerates. The area is also known for its extensive wetlands and mangrove forests.

Sapele experiences a tropical climate with high levels of rainfall. The region has two distinct seasons: the dry season, which typically runs from November to April, and the rainy season, which lasts from May to October. The high humidity and significant rainfall contribute to the lush vegetation and dynamic ecosystem found in the area. The combination of the region's geology and climate has also made the Niger Delta a significant oil-producing area, with a complex network of oil reservoirs beneath the sedimentary layers. This has both shaped the local economy and posed environmental challenges due to the impact of oil extraction on the delicate ecosystem of the region.

2.2 Population of Samples

The soil and plant samples used in this study were randomly selected from farmland around crude oil exploration sites in Edo State. The population of this study includes all the farmland around crude oil exploration sites in Edo State. A thirty sampling sites were randomly selected in the study area for the collection of soil and plant samples. A total of sixty samples (thirty each of soil and plant) were collected from the study area and were analysed for heavy metal concentration and activity concentration analysis. The background exposure level was determined for all the sampling points.

2.3 Method of Soil Sample Collection

A total of thirty (30) soil samples were collected from farms in Sapele, Delta State. These samples were collected randomly from each sampling farms around the oil exploration sites. Soil samples were collected at 50 m apart from each farm. The method to be applied in sampling is simple random sampling to achieve statistical sensitivity of sampling. A shovel would be used to collect soil samples to a depth of about 10 cm. Each composite soil sample to be collected is expected to weigh about 400g of mass will be separately collected and placed in a well-labeled polythene bag, and then sealed to avoid cross-contamination of the samples during transportation to the laboratory.

2.4 Method of Plant Sample Collection

A total of thirty (30) plant samples were collected from farms around the crude oil exploration sites in Edo State. These samples were collected randomly from each sampling farms around the oil exploration sites. Plant samples were collected at 50 m apart from each farm, same way as soil sample collection. The method to be applied in sampling is simple random sampling to achieve statistical sensitivity of sampling. A cutlass was used to collect plant samples, which will consist of the root, stem, and leaves of the plant. Each composite plant sample to be collected is expected to weigh about 600g of mass and would be separately collected and placed in a well-labeled polythene bag, and then sealed to avoid cross-contamination of the samples during transportation to the laboratory.

2.5 Method of Soil and Plant Sample Preparation

The soil and plant samples would be prepared through a process of open-air drying at room temperature to remove moisture and would later be oven-dried at a temperature of 500 – 1100 °C to obtain uniform weight. Stony soil samples and plant samples would be ground into powdery form separately and singly using a mortar and pestle and sieved with a wire mesh with holes of thickness 0.5 mm to obtain homogeneity of sample size. The sample will be shared into each making and total of sixty samples. The samples are expected to weigh approximately 300g. The group of samples for activity concentration analysis would be kept in well-labeled sealed polythene bags for 28 days to attain secular equilibrium between ^{238}U, ^{232}Th, and ^{40}K and their progeny before taking them to the laboratory for NaI(Tl) analysis. On the other hand, the samples for heavy metal concentration analysis will be sent immediately to the laboratory, where XRF spectrometry analysis will be carried out on the samples.

2.6 Method of Data Collection

Soil and plant samples collected from farmland around the selected crude oil exploitation sites in Edo State were analyzed to determine the radioactivity concentration levels of ^{238}U, ^{232}Th, and ^{40}K, and heavy metal concentration analysis using a NaI(Tl) detector and XRF spectrometer. The Gamma ray spectroscopy with a well-calibrated NaI (Tl) detector system at the Centre for Energy Research and Training (CERT) Laboratory, Ahmadu Bello University, Zaria. The XRF spectrometry system at the central laboratory, Kaduna State Polytechnic, Kaduna. The Global Positioning System (GPS) was used to track the data record and provide geo-location information. All samples were properly packed and marked with their identification code. The results were presented in tables for simple and clear representation.

2.7 Method of Data Analysis

The data on radioactivity concentration and heavy metal concentration from soil and plant samples were analyzed. The hazard indices and soil to plant transfer factor due to the presence of heavy metals and activity concentration, level, respectively, were determined to ascertain the potential risk associated with the samples. MS Excel was used for the data analysis.

2.7.1 Hazard indices Determination of Heavy Metals Analysis

The potential exposure pathways for heavy metals in contaminated soils are calculated based on recommendations by several U.S Environmental Protection Agency [33]. ADI (mg/kg-day) for the different pathways was calculated using the following exposure Equations (1) to (3).

The ingestion of Heavy Metals through Soil (ADI_{ing}), Inhalation of Heavy Metals via Soil Particulates (ADI_{inh}), and Dermal Contact with Soil (ADI_{derm}) are given in equations 1, 2, and 3, respectively.

$$ADI_{ing} = \frac{CxIRxEFxEDxCF}{BWxAT} \quad 1$$

where ADI_{ing} is the average daily intake of heavy metals ingested from soil in mg/kg-day, C is the concentration of heavy metal in mg/kg for soil. IR in mg/day is the ingestion rate, EF in days/year is the exposure frequency, ED is the exposure duration in years, BW is the body weight of the exposed individual in kg, and AT is the time period over which the dose is averaged in days. CF is the conversion factor in kg/mg.

$$ADI_{inh} = \frac{CxIR_{air}xEFxED}{BWxATxPEF} \quad 2$$

where ADI_{inh} is the average daily intake of heavy metals inhaled from soil in mg/kg-day, CS is the concentration of heavy metal in soil in mg/kg, IR_{air} is the inhalation rate in m^3/day, and PEF is the particulate emission factor in m3/kg. EF, ED, BW, and AT are as defined earlier in Equation 1.

$$ADI_{dems} = \frac{CxSAxFExAFxABSxEFxEDxCF}{BWxAT} \quad 3$$

Where ADI_{dems} is the exposure dose via dermal contact in mg/kg/day. CS is the concentration of heavy metal in soil in mg/kg, SA is the exposed skin area in cm^2, FE is the fraction of the dermal exposure ratio to soil, AF is the soil adherence factor in mg/cm^2, and ABS is the fraction of the applied dose absorbed across the skin. EF, ED, BW, CF, and AT are as defined earlier in Equation 1. Table 3.1 shows the exposure parameters used for the health risk assessment for the standard residential exposure scenario through different exposure pathways.

Table 1. Exposure parameter used for the health risk assessment through different exposure pathways for soil [34].

Parameter	Unit	Child	Adult
Body weight (BW)	Kg	15	70
Exposure Frequency (EF)	Days/ years	350	350
Exposure duration (ED)	Years	6	30
Ingestion rate (IR)	mg/day	200	100
Inhalation rate (IRair)	m^3/day	10	20
Skin surface area (SA)	cm^2	2100	5800
Soil adherence factor (AF)	mg/ cm^2	0.2	0.07

Dermal absorption factor (ABS)	None	0.1	0.1
Dermal exposure ratio (FE)	None	0.61	0.61
Particulate emission factor (PEF)	m^3/ kg	$1.3x10^9$	$1.3x10^9$
Conversion factor (CF)	kg/ mg	10^{-6}	10^{-6}
Average time (AT) for carcinogens	Days	365x70	365x70
Average time (AT) for non-carcinogens	Days	365xED	365xED

2.7.2 Non- Non-Non-Carcinogenic Risk Assessment

Non-carcinogenic hazards are characterized by a term called hazard quotient (HQ). HQ is a unitless number that is expressed as the probability of an individual suffering an adverse effect. It is defined as the quotient of ADI or dose divided by the toxicity threshold value, which is referred to as the chronic reference dose (RfD) in mg/kg-day of a specific heavy metal, as shown in Equation 4;

$$HQ = \frac{ADI}{RFD} \quad 4$$

For n number of heavy metals, the non-carcinogenic effect on the population is a result of the summation of all the HQs due to individual heavy metals. This is considered to be another term called the Hazard Index (HI) as described by USEPA document [34]. Equation 5 shows the mathematical representation of this parameter:

$$HI = \sum_{k=1}^{n} HQ_k = \sum_{k=1}^{n} \frac{ADI_k}{RfD_k} \quad 5$$

where HQ_k, ADI_k, and RfD_k are values of heavy metal k. If the HI value is less than one, the exposed population is unlikely to experience adverse health effects. If the HI value exceeds one, then there may be concern for potential non-carcinogenic effects [34-35].

2.7.3 Carcinogenic Risk Assessment

For carcinogens, the risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The equation for calculating the excess lifetime cancer risk is:

$$Risk_{pathway} = \sum_{k=1}^{n} ADI_k CSF_k \quad 6$$

where Risk is a unitless probability of an individual developing cancer over a lifetime. ADIk (mg/kg/day) and CSF_k $(mg/kg/day)^{-1}$are the average daily intake and the cancer slope factor, respectively, for the k^{th} heavy metal, for n number of heavy metals. The slope factor converts the estimated daily intake of the heavy metal averaged over a lifetime of exposure directly to the incremental risk of an individual developing cancer (U.S. Environmental Protection Agency, 1989; Caspah, 2016).

The total excess lifetime cancer risk for an individual is finally calculated from the average contribution of the individual heavy metals for all the pathways using the following equation:

$$Risk_{(total)} = Risk_{(ing)} + Risk_{(inh)} + Risk_{(dems)} \quad 7$$

where Risk(ing), Risk(inh), and Risk(dermal)are risk contributions through ingestion, inhalation, and dermal pathways.

Both non-carcinogenic and carcinogenic risk assessment of heavy metals are calculated using RfD and CSF values derived largely from the Department of Environmental Affairs (South Africa) and USEPA, as shown in Table 2.

Table 2. Reference doses (RfD) and Cancer Slope Factors (CSF) for the different heavy metals [32-36].

Heavy metal	Oral RfD	Dermal RfD	Inhalation RfD	Oral CSF	Dermal CSF	Inhalation CSF
As	$3.0x10^{-4}$	$3.0x10^{-4}$	$3.0x10^{-4}$	1.5	1.5	15
Pb	$3.6x10^{-3}$	NA	NA	$8.5x10^{-3}$	NA	$4.2 x 10^{-2}$
Cd	$5.0x10^{-4}$	$5.0x10^{-4}$	$5.7x10^{-5}$	NA	NA	6.3
Ni	$2.0x10^{-2}$	$5.6x10^{-3}$	NA	NA	NA	NA
Zn	$3.0x10^{-1}$	$7.5x10^{-2}$	NA	NA	NA	NA
Pb	$3.5x10^{-3}$	NA	NA	NA	NA	NA
Cu	$4x10^{-2}$	NA	NA	NA	NA	NA
Cr	$3x10^{-3}$	NA	NA	$5x10^{-1}$	NA	NA

3 Results and Discussion

The results of heavy metal concentration in soil and plant samples collected from the study area are presented in Figures 1 and 2, respectively. The levels of Chromium (Cr), Lead (Pb), Nickel (Ni), Zinc (Zn), and Copper (Cu) in all the soil and plant samples collected were measured.

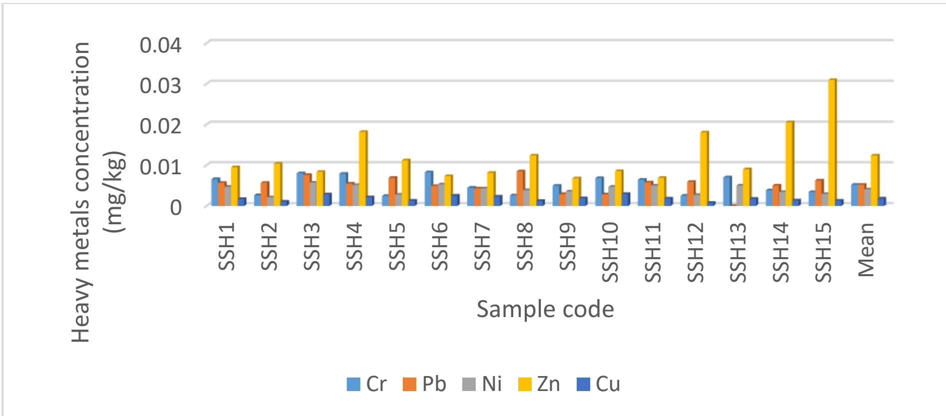

Fig. 1: Chart of heavy metal concentration in soil samples collected from the study area.

Figure 1 presents the result of heavy metal concentration in soil samples collected from the study area. The concentration of Cr, Pb, Ni, Zn, and Cu ranged from 0.002462 to 0.008249 mg/kg, 0 to 0.008506 mg/kg, 0.002145 to 0.005747 mg/kg, 0.006771 to 0.030923 mg/kg, and 0.000783 to 0.002947 mg/kg, respectively. The mean concentrations are 0.005197933 mg/kg, 0.005183467 mg/kg, 0.004088067 mg/kg, 0.012421133 mg/kg, and 0.001799733 mg/kg, respectively.

Chromium levels are far below the regulatory standard, indicating negligible chromium pollution. The measured lead concentrations in the study area are negligible compared to the regulatory limits, suggesting a low risk of lead-related toxicity. The nickel concentrations are substantially lower than the allowable limits, indicating a minimal contribution from such sources. The concentrations of zinc in the study area are significantly below the permissible threshold, indicating no substantial zinc enrichment and suggesting that agricultural or industrial contributions are minimal. The measured copper levels are extremely low, far below the regulatory limits, pointing to an unpolluted environment with respect to copper. The concentrations of all analyzed heavy metals are well below their respective permissible limits. This indicates that the study area's soil is not significantly contaminated by heavy metals.

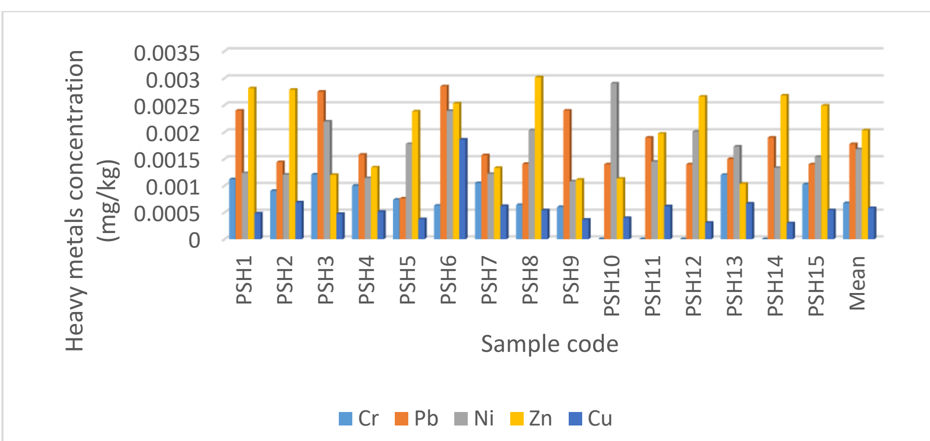

Fig.2: Chat of heavy metal concentration in plant samples collected from the study area.

Figure 2 shows the heavy metal concentration in plant samples collected from the study area. The mean concentrations of Cr, Pb, Ni, Zn, and Cu are 0.001025 mg/kg, 0.0014 mg/kg, 0.001541 mg/kg, 0.002491 mg/kg, and 0.000539 mg/kg, respectively. The values ranged from 0.00121 to 0.000674867 mg/kg, 0.00285 to 0.001777333 mg/kg, 0.0029 to 0.0016838 mg/kg, 0.003016 to 0.002032527 mg/kg, and 0.001862 to 0.0005834, respectively.

The measured mean concentration of Cr (0.001025 mg/kg) is significantly below the permissible limit (2.3 mg/kg). The mean concentration of Pb (0.0014 mg/kg) is far below the permissible limit (0.3 mg/kg), suggesting no significant Pb pollution in the study area. The mean concentration of Ni (0.0014 mg/kg) is far below the permissible limit (0.3 mg/kg), suggesting no significant Pb pollution in the study area. The measured concentration of Zn (0.002491 mg/kg) is well below the permissible limit (50 mg/kg). The measured value (0.000539 mg/kg) is far

below the permissible limit (10 mg/kg). The heavy metal concentrations in the plants are significantly lower than the WHO permissible limits, indicating that the farmland in the study area is not heavily contaminated by these metals.

3.1 Soil-to-Plant Transfer Factor

The result of two soil-to-plant transfer factor was calculated for Cr, Pb, Ni, Zn, and Cu. The Soil to Plant Transfer Factor (TF) is a crucial parameter in environmental studies, indicating the efficiency with which plants uptake heavy metals from the soil. It is defined as the ratio of the concentration of a heavy metal in the plant to its concentration in the soil. This factor helps in understanding the potential risk of heavy metal contamination in the food chain. The calculated transfer factors are presented in Figure 3.

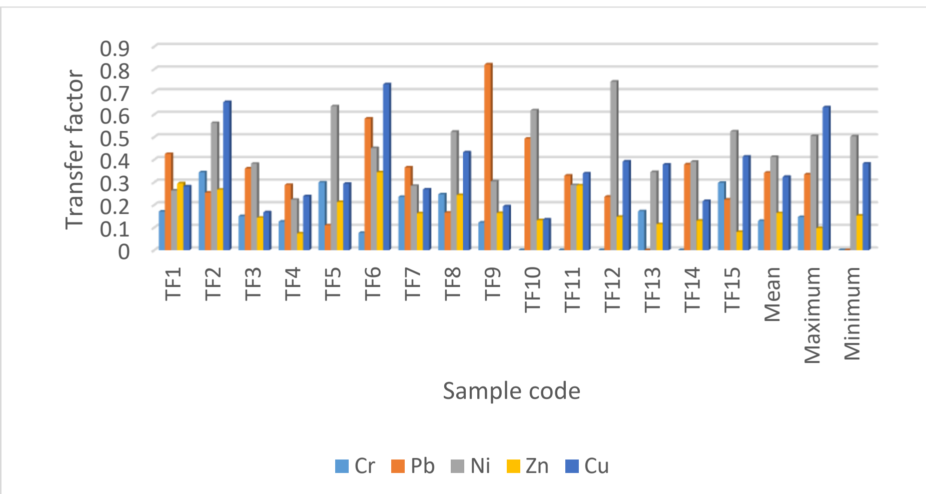

Fig. 3: Soil-to-plant transfer collected from the study area.

Figure 3 presents the soil-to-plant transfer collected from the study area. The mean transfer factors of Cr, Pb, Ni, Zn, and Cu are 0.12983366, 0.342885048, 0.411881704, 0.163634563, and 0.324159195, respectively. The values ranged from 0 to 0.146684447, 0 to 0.335057606, 0.503496503 to 0.504611101, 0.152857776 to 0.097532581, and 0.383141762 to 0.631828979, respectively. Cr, Pb, and Zn exhibit relatively low to moderate transfer factors, suggesting that they are less bioavailable in the soil and pose minimal immediate risk of accumulation in plants. Ni and Cu. The relatively high transfer factors for Ni (with some values exceeding 0.5) and Cu (with a range including values above 0.5) indicate significant bioavailability, raising concerns about potential toxicity in plants and subsequent risks to human and animal consumers.

3.2 Non- Non-Carcinogenic Risk Assessment of Heavy Metals

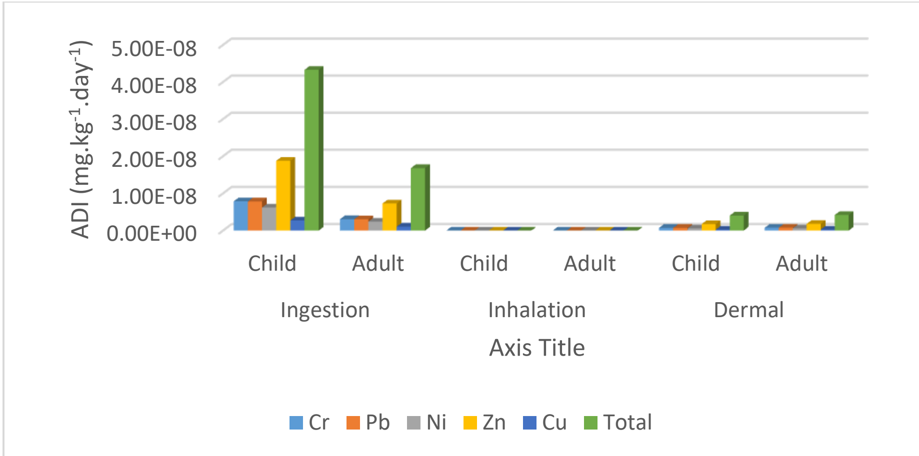

Fig. 4: Chart of mean annual daily intake of soil samples collected from the study area.

Figure 4 presents the mean annual daily intake of soil samples collected from the study area. The Annual Daily Intake (ADI) is a key parameter in assessing human exposure to contaminants through various pathways: ingestion, inhalation, and dermal contact. This analysis evaluates the reported ADI values for **Cr,** Pb, Ni, Zn, and Cu for children and adults, focusing on potential risks. The mean ADI for ingestion in Child (Adult) are 7.845E-09 (3.05 x 10^{-9}), 7.8241 x 10^{-9} (3.04 x 10^{-9}), 6.17 x 10^{-9} (2.40 x 10^{-9}), 1.87 x 10^{-8} (7.29 x 10^{-9}), 2.71 x 10^{-9} (1.05 x 10^{-9}), and 4.33 x 10^{-8} (1.68 x 10^{-8}), respectively. The mean ADI for inhalation in Child (Adult) are 1.09 x 10^{-12} (4.69 x 10^{-13}), 1.09 x 10^{-12} (4.68 x 10^{-13}), 8.61 x 10^{-13} (3.69 x 10^{-13}), 2.61 x 10^{-12} (1.12 x 10^{-12}), 3.79 x 10^{-13} (1.62 x 10^{-13}), and 6.05 x 10^{-12} (2.59 x 10^{-12}), respectively. The mean ADI for dermal in Child (Adult) are 7.29 x 10^{-10} (7.56 x 10^{-10}), 7.27 x 10^{-10} (7.54 x 10^{-10}), 5.74 x 10^{-10} (5.94 x 10^{-10}), 1.74 x 10^{-9} (1.80 x 10^{-9}), 2.52 x 10^{-10} (2.62 x 10^{-10}), and 4.03 x 10^{-9} (4.17 x 10^{-9}), respectively.

Ingestion pathway is the primary exposure route for all metals, with ADI values significantly higher than those for inhalation or dermal pathways. Zn has the highest ADI values among the metals, indicating its relatively high presence and bioavailability in the studied samples. The ADI values for children are consistently higher than those for adults, reflecting higher exposure due to lower body weight and increased intake relative to body mass. ADI values for inhalation are several orders of magnitude lower than those for ingestion, suggesting minimal exposure via this route. Among the metals, Zn has the highest inhalation ADI, but the values are still negligible in terms of health risk.

Dermal exposure ADIs are higher than inhalation but lower than ingestion. Cu and Zn exhibit higher dermal ADI values compared to other metals, likely due to their bioavailability and potential for skin absorption.

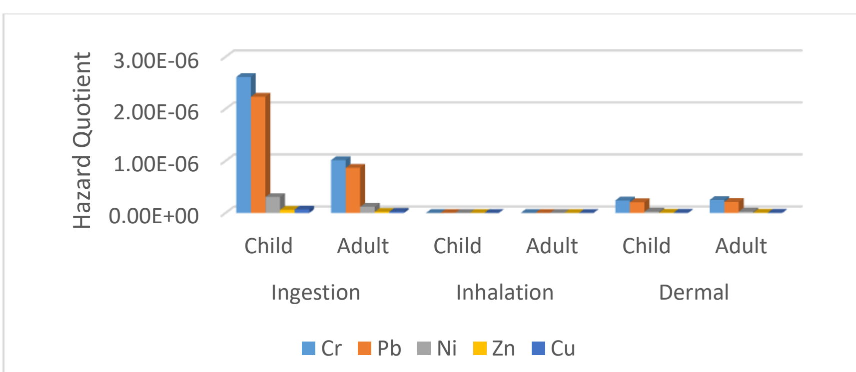

Fig. 5: Chat of calculated mean hazard quotient of heavy metals in soil samples collected from the study area.

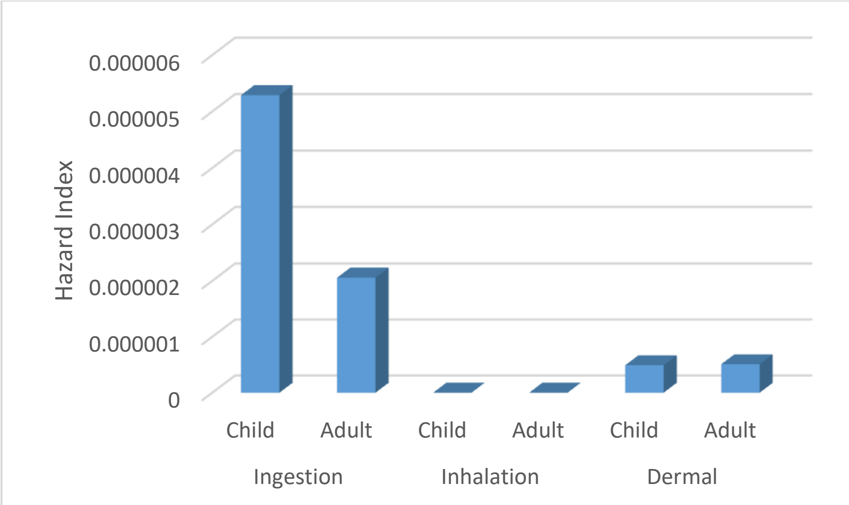

Fig. 6: Chat of calculated mean hazard index of heavy metals in soil samples collected from the study area

Figure 7 presents the calculated mean hazard quotient and hazard quotient of heavy metals in soil samples collected from the study area. The Hazard Quotient (HQ) evaluates the potential non-carcinogenic risk associated with exposure to heavy metals. It is the ratio of the estimated dose (e.g., ADI) to the reference dose (RfD). An HQ value less than 1 indicates negligible risk, while an HQ greater than 1 suggests potential health concerns.

The calculated mean hazard quotient for Cr, Pb, Ni, Zn, and Cu. The mean HQ for ingestion in Child (Adult) are 2.61531E-06 (1.02 x 10^{-6}), 2.23 x 10^{-6} (8.69 x 10^{-7}), 3.08 x 10^{-7} (1.20 x 10^{-7}), 6.25 x 10^{-8} (2.43 x 10^{-8}), and 2.43 x 10^{-8} (2.64 x 10^{-8}), respectively. The mean HQ for inhalation in Child (Adult) are 3.65 x 10^{-10} (1.56 x 10^{-10}), 3.12 x 10^{-10} (1.34 x 10^{-10}), 4.31 x 10^{-11} (1.85 x 10^{-11}), 8.73 x 10^{-12} (3.73 x 10^{-12}), and 9.48 x 10^{-12} (4.06 x 10^{-12}), respectively. The mean HQ for dermal in Child (Adult) are 2.43 x 10^{-7} (2.51 x 10^{-7}), 2.08 x 10^{-7} (2.15 x 10^{-7}), 2.86 x 10^{-8} (2.97 x 10^{-8}), 5.81 x 10^{-9} (6.02 x 10^{-9}), and 6.31 x 10^{-9} (6.54 x 10^{-9}), respectively.

Cr and Pb have the highest ingestion HQ values for both children and adults compared to other metals, indicating relatively higher exposure risks. HQ values for children are consistently higher than those for adults due to their lower body weight and higher intake relative to body size. HQ values for ingestion remain far below 1, suggesting minimal risk.
HQ values for inhalation are significantly lower than ingestion and dermal pathways for all metals. The highest inhalation HQ values are for Cr and Pb, but they remain negligible compared to the threshold of 1.
HQ values for dermal exposure are higher than inhalation but lower than ingestion. **Cr** and **Pb** again show the highest HQ values in this pathway, although all remain below 1, indicating no significant dermal risk. Children have higher HQ values across all pathways due to their greater vulnerability to heavy metal exposure.
The hazard index (HI) is a dimensionless parameter used to assess non-carcinogenic health risks posed by chemical exposure via ingestion, inhalation, or dermal contact. An HI value below 1 indicates no significant risk, while a value above 1 suggests potential health concerns. The mean hazard index (HI) for ingestion, inhalation, and dermal contact of children (adults) is 5.29 x 10^{-6} (2.06 x 10^{-6}), 7.38 x 10^{-10} (3.16 x 10^{-10}), and 4.919 x 10^{-7} (5.09 x 10^{-7}), respectively.
The HI for ingestion is higher than for other exposure routes for both children and adults. Children have a greater HI than adults, likely due to higher intake rates relative to body weight and behaviors such as hand-to-mouth activity. This makes ingestion a primary pathway of concern for children. However, both values are significantly below 1, indicating minimal non-carcinogenic health risks from ingestion for both groups.

The inhalation pathway shows the lowest HI among the three exposure routes for both groups. The values for children are slightly higher than for adults, possibly due to higher respiratory rates relative to body size. The extremely low HI values suggest that inhalation poses negligible non-carcinogenic risks.

Unlike ingestion and inhalation, the dermal contact HI is slightly higher for adults than for children. This could result from factors like longer exposure durations or differences in skin absorption rates modeled for adults. Despite this, the values remain orders of magnitude below 1, suggesting that dermal contact is a low-risk pathway for both populations.

3.3 Carcinogenic Risk Assessment of Heavy Metals

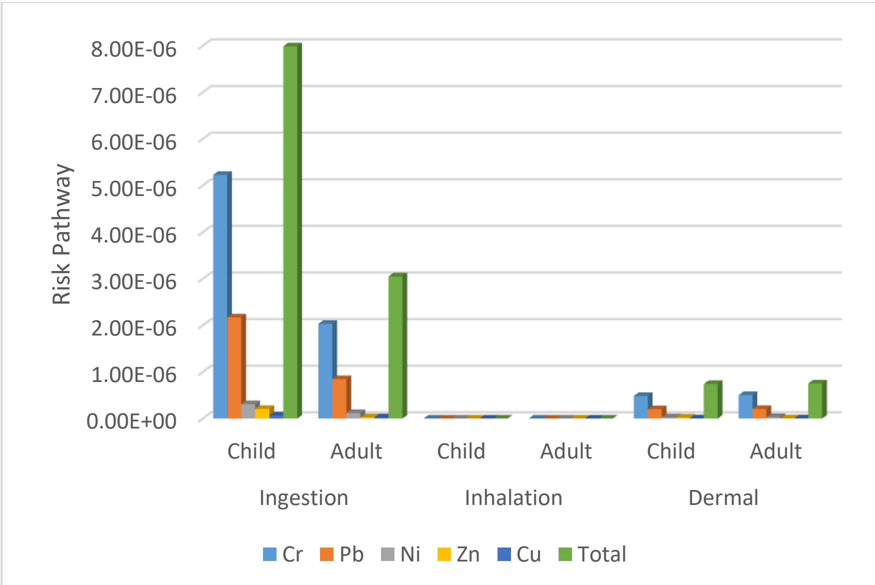

Fig. 7: Chat of calculated risk pathway of heavy metal concentration in soil sample collected from the study area.

Figure 7 presents the calculated risk pathway of heavy metal concentration in the soil sample collected from the study area. The mean risk pathway for ingestion in Child (Adult) are 5.23 x 10^{-6} (2.03 x 10^{-6}), 2.17 x 10^{-6} (8.45 x 10^{-7}), 3.08 x 10^{-7} (1.20 x 10^{-7}), 2.08 x 10^{-7} (2.43 x 10^{-8}), and 6.79 x 10^{-8} (2.64 x 10^{-8}), respectively. The mean risk pathway for inhalation in Child (Adult) are 7.30 x 10^{-10} (3.13 x 10^{-10}), 3.03 x 10^{-10} (1.30 x 10^{-10}), 4.31 x 10^{-11} (1.85 x 10^{-11}), 2.91 x 10^{-11} (3.74 x 10^{-12}), and 9.48 x 10^{-12} (4.06 x 10^{-12}), respectively.

The ingestion risk is highest for Chromium (Cr), followed by Lead (Pb), Nickel (Ni), Zinc (Zn), and Copper (Cu). Children's risk is consistently higher than adults for all metals, as expected due to their lower body weight and higher exposure-to-body-mass ratio. Chromium (Cr) exhibits the highest risk for inhalation, followed by Lead (Pb), Nickel (Ni), Zinc (Zn), and Copper (Cu). Similar to ingestion, children's inhalation risks are higher than those for adults, though the differences are less pronounced. Chromium (Cr) again has the highest dermal hazard index (HI), followed by Lead (Pb), Nickel (Ni), Zinc (Zn), and Copper (Cu). Interestingly, for dermal contact, adult risks are comparable to or slightly higher than those for children, particularly for Chromium and Lead.

4 Conclusion

The study concludes that the levels of natural radioactivity in soil and plants from the oil-producing area of Delta State are within internationally acceptable safety limits. The absorbed dose rate, Ra_{eq}, H_{ex}, and AEDE values suggest no immediate radiological hazard. However, the slightly elevated ELCR value points to a marginal increase in lifetime cancer risk, which calls for ongoing monitoring and precautionary measures. Additionally, the presence of heavy metals in soil and plants needs further investigation, as prolonged exposure could pose potential health risks. The study underscores the need for sustainable environmental management in oil exploration regions to prevent long-term contamination.

Reference

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