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# Ecological and Human Health Risk Assessment of Heavy Metal in Surface Soils in Makurdi Metropolis, Nigeria

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## Abstract

Ecological and Human Health Risk Assessment of Heavy Metals Pollution in Surface Soils in Makurdi Metropolis was investigated. Soil samples were collected from five different locations namely: Rice Mills, Industrial layout Naka Road, BSU Teaching Hospital, Mechanic Village Apir, and Mechanic Village North Bank within Makurdi metropolis. The results of the physicochemical properties indicate that, pH ranged from 6.56 to 6.95 which is below WHO limits of 6.5–8.5. Other soil properties such as Electrical Conductivity (EC), cationic exchange capacity (CEC) showed the range of 43.5-68.2 and 7021-18771 respectively. Heavy metals Concentration in the samples were quantitatively determined using atomic absorption spectrometry (AAS). The results showed that the concentrations (mg/kg) of heavy metals range from FE (0.167–3.16), Zn (0.038–0.248), Ni (0.116–0.92), Pb (0.795–45.7), Cu (0.236–0.506). The results were within WHO permissible limit excerpt that of Pb. Results of ecological risk indices showed that Igeo of all the selected metals in the study soils were unpolluted suggesting that soils in the sample areas have natural background levels for these metals excerpt Pb in Apir Mechanic Workshop (0.926) and North Bank (0.401) that indicate moderately polluted level. The contamination factor ($C_f$) of the elements in all the sampling sites was below 1 indicating low contamination of the studied soil excerpt Pb in Rice Mill, Teaching Hospital, Apir Mechanic Workshop and North Bank sites having showing moderate contamination. The enrichment factor values for the element range from moderate enrichment, moderately severe enrichment, extremely severe enrichment, severe enrichment for Zn, Ni, Pb and Cu respectively. The ecological risk indexes for all the elements in the study area were below 150 which mean the soils in the study sites were of low ecological risk. The results showed that chronic daily intake (CDI) of metals were in the following order Pb < Fe < Cu < Ni < Zn for both adults and children. The Hazard Quotient (HQ) and Hazard Index (HI) values remain below one for all three pathways (ingestion, dermal and inhalation), indicates that, there is no evident risk of chronic health effects to the age group. Hence, the population under study is considered to be safe from the heavy metals. The cancer risk due to Ni intake estimated in this study in all the entry routes range from $1.08\times10^{-7}$ to $4.39\times10^{-12}$ while that of Pb range from $1.78\times10^{-7}$ to $1.39\times10^{-12}$ across the age group respectively. These values fall below the range of predictable risk to cancer. Therefore, it is recommended that there should be continuous monitoring of heavy metals around the study areas to ascertain the health risk that may occur due to heavy metal accumulation

***Keywords:*** Heavy metals; Geoaccumulation; Contamination; Pollution; physicochemical; Health risk

## 1. Introduction

The environment and its compartments have been severely polluted by heavy metals (Saikat et al., 2022). This has compromised the ability of the environment to foster life and render its intrinsic values. Heavy metals are known to be naturally occurring compounds but anthropogenic activities introduce them in large quantities in different environmental compartments. This leads to the environment's ability to foster life being reduced as human, animal and plant health become threatened. This occurs due to bioaccumulation in the food chains as a result of the non-degradable state of the heavy metals (Vhahangwele and Khathutshelo, 2018). According to literature, any naturally occurring element having an atomic number and elemental density greater than 5 g cm−3 is regarded as a heavy metal. These metals include: Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Zn and elements within the platinum group. These elements have a very fine line of toxicity and essentiality to living organisms. On exposure, these elements can pose hazardous effects to living organisms due to their toxicity and are listed as priority pollutants by numerous organizations and regulatory entities (Rai et al., 2019; Zwolak et al., 2019). The benefits of heavy metals are generally outweighed by their hazards, for example, carcinogenicity is promoted by high exposure to antimony and chromium (Sun et al., 2015), lead poisoning causes intellectual abnormalities in children. Mercury toxicity causes Minamata disease, while cadmium poisoning causes itai-itai disease. (Hou et al., 2013). Soil pollution by heavy metals is becoming a critical environmental concern due to industrial revolution and urbanization (Alengebawy et al., 2021). The persistent and non-biodegradable nature of metal (loid)s facilitates their accumulation in the soil and can poses harmful effects on the human health (Sarwar et al., 2017). The distribution of heavy metals in soils is associated with both natural and anthropogenic inputs. Natural sources include volcanic eruptions, geological weathering of parent rock materials, etc. Whereas, anthropogenic sources of heavy metals are extensive use of fertilizers and pesticides in agriculture farms, mining and smelting of metals, industrial emissions, aerosol deposition, spillage of petrochemicals, leaded gasoline and paints, and atmospheric deposition (Chibuike and Obiora, 2014). Of the utmost importance in evaluating soil management is quantifying the ecological risk of soil pollution. Using soil pollution indices, such as enrichment factor (EF), geoaccumulation index (Igeo) and pollution load index (PLI) etc. gives information on the soil (Men et al., 2018; Khademi et al., 2019; Adimalla et al., 2020; Egbueri et al., 2020; Monged et al., 2020). The potential ecological risk can be estimated based on the risk index (RI) for each sample. Also, the risks from individual metals, which contribute to the ecological risk can be identified (Men et al., 2018; Gan et al., 2019; Li et al., 2020; Monged et al., 2020). Concerning the human health risk of heavy metals, certain metals are essential for life and play irreplaceable roles as sources of vitamins and minerals in the functioning of the body's organs (Kamunda et al., 2016; Nde and Mathuthu, 2018). All living organisms require varying amounts of metals however, these becomes toxic at higher concentrations (Lane and Morel, 2009). Some elements have no role in maintaining the homeostasis of the body and are directly toxic, among them are Cd, As, Hg and Pb, which form the subject of special monitoring because of the risks they present for human health (Mohammadi et al., 2019). Once absorbed by the body, heavy metals continue to accumulate in vital organs such as brain, liver, bones and kidneys for years or decades resulting to serious health consequences (Kabata-Pendias, 2011). Therefore, the accumulation of heavy metals in the soil and human

being must be studied and monitored regulatory due to the persistent and potentially toxic nature of these elements.

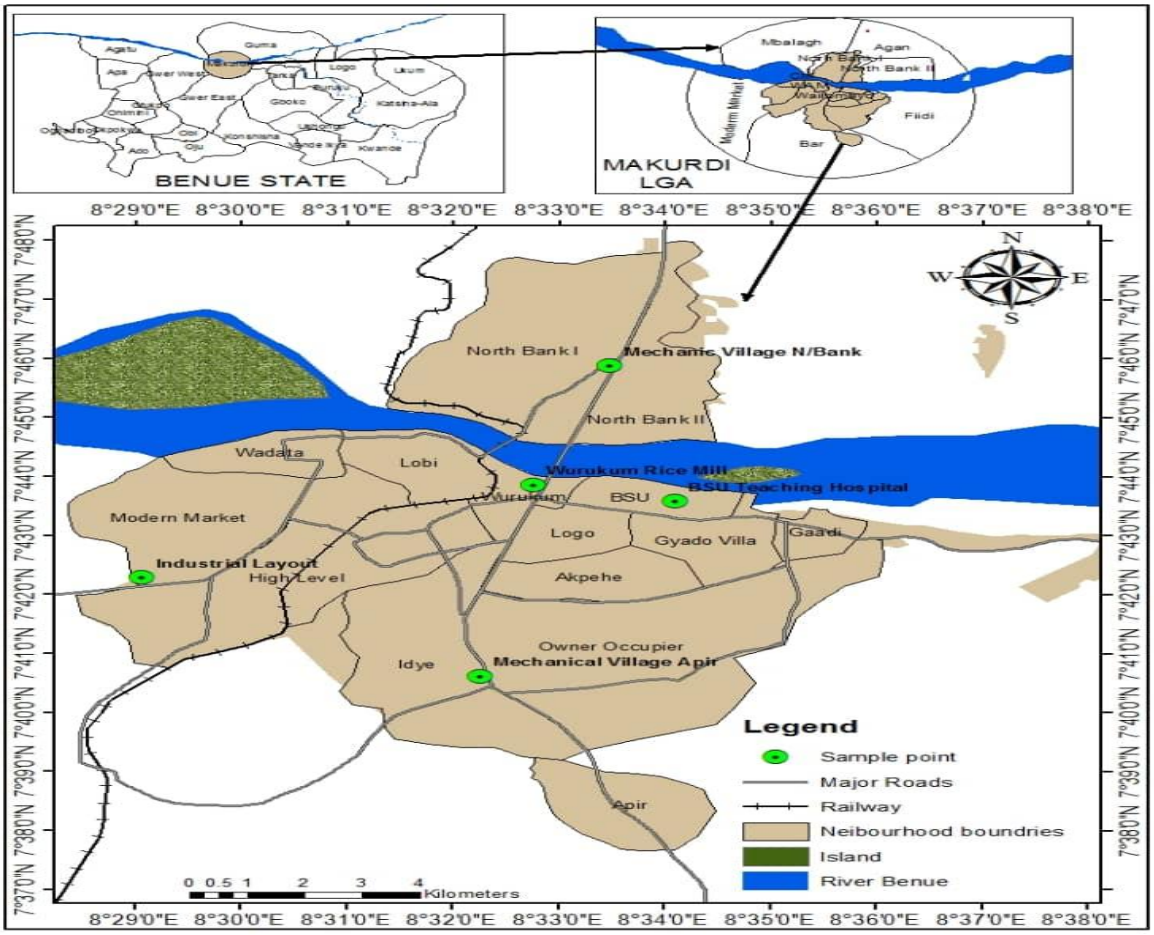



**Figure 1:** Map showing the Makurdi Metropolis

## 2. Materials and methods

### *2.1 Sample collection*

Soil samples were collected from five different locations namely: Industrial layout Naka Road, Mechanic Village Apir, Mechanic Village North Bank, BSU Teaching Hospital and Wurukum rice mills within Makurdi metropolis. At each sampling point, top soil at the depth of 0-20 cm was collected with a steel augur. At each sampling location five replicate samples were collected within a 2 m by 2 m grid thoroughly mixed to obtain a homogenous sample out of which 2 kg was packed into labeled polyethylene bags and transported to the Chemistry Laboratory of Joseph Sarwuan Tarkaa Makurdi for further analysis.

### *2.2 Sample preparation*

The collected samples were oven at 65 ◦C for 120-150 min, crush with mortal and be sieved and store in polyethylene containers for analysis of the heavy metal concentration. Exactly 1.0 g of the dried and sieved soil sample was weighed into 250 mL conical flask. A known amount of freshly prepared aqua-regia (HCl: HNO3) in a ratio of 1:3 was added (Goddard and Brown, 2014). The beaker was covered with a filter paper; the solution will be heated for 1 hour using a hot plate. The mixture was allowed to cool and filter with Whatman filter paper into a 50 mL standard volumetric flask, the filtrate will be diluted to 50 mL with de-ionized distilled water. This procedure was repeated for all the soil samples.

### *2.3 Physicochemical Parameters*

#### *2.3.1 The pH measurement*

The concentration of hydrogen ion is determined by measuring the pH. In the beaker which contains 10 g of the soil sample (soil), 100 mL deionized H2O was transferred for the 1:10 suspension and this solution was stirred continuously in a shaker for 30 min and the soil sample was allowed to settle and measurement of pH will be carried out by using supernatant. The pH was measured using glass electrode pH meter.

#### *2.3.2 Determination of cation exchange capacity*

The CEC of representative soil per 100 g expressed in milli equivalent and which is the number of cations that neutralized the negative charge is measured. In the clean beaker (500 mL) which contains NH4OH of 250 mL, soil sample (10 g) was weighed and shaken within the thirty min. The sample was allowed to stand f0r 24 hours and the solution was filtrate using filter paper in the plastic bottle. By washing of the residue repeatedly with ethanol, the excess NH4OH was removed. By using the NaCl solution (30 mL), then washed residue was leached improved the displacement of adsorbed NH4 1N and 250 mL leachate was collected by repeating of leaching (Akan et al., 2010). The CEC was then calculated as follows; The CEC was then calculated as follows; The CEC was then calculated as follows:

$$\text{CEC (cmol /kg) of Soil} = \frac{VB - VS \times N \times 100 mcf}{S} \quad \text{----------(1)}$$

where,
VB = volume of the blank,
VS = Sample volume,
N = NaOH's normality,
S = weight of sample,
mcf = moisture correction factor

### 2.4 Sample Analysis

The digested soil samples were analyzed for the presence of heavy metals using Atomic Absorption Spectrophotometer.

### *2.5 Health Risk Assessment*

There are three common pathways for exposure to heavy metals related to indoor dust including ingestion (Ing), inhalation (Inh) and dermal contact (Der). Equations below were used to calculate dose received via each of these exposure pathways:

$$\mathrm{CDI_{Ing}} = \frac{\mathrm{C \times IngR \times EF \times ED}}{\mathrm{BW \times AT}} \times 10^{-6} \text{ ----------(2)}$$

$CDI_{Ing}$ and C are the dose contacted through ingestion (mg/kg/day) and exposure point content (mg/kg) of the analyzed elements, respectively. IngR (mg/day) is the ingestion rate (200 for children and 100 for adults, CF is the conversion factor, EF (days/year), ED (years), BW (kg) and AT are the exposure relative frequency, exposure duration (6 for children and 24 for adults), average body weight (15 for children and 70 for adults) and averaging time (exposure duration 365 days for non-carcinogens), respectively.

$$\mathrm{CDI_{Inh}} = \frac{\mathrm{C \times InhR \times EF \times ED}}{\mathrm{PEF \times BW \times AT}} \text{ ----------(3)}$$

Where,

$\mathrm{CDI_{Inh}}$ (mg/kg/day) is the dose contacted through inhalation.
InhR ($m^3$/day) is the inhalation rate (7.60 for children and 20.00 for adults)
EF is the exposure frequency
ED is the exposure duration
BW is the body weight
AT is the averaging time.

$$\mathrm{CDI_{Der}} = \frac{\mathrm{C \times SA \times Kp \times ET \times EF \times ED \times ABS}}{\mathrm{BW \times AT}} \times 10^{-6} \text{ ----------(4)}$$

Where,

$\mathrm{CDI_{der}}$ (mg/kg/day) is the dose absorbed via dermal contact with indoor dust
SA ($cm^2$) are the exposed skin area (2800 for children and 5700 for adults),
AF represents the soil adherence factor in mg/cm2,
CF is the kg/mg conversion Factor,
FE represents the proportion of the dermal exposure ratio to soil,
ABS dermal absorption factor (0.001) for all analysed elements, respectively

#### *2.5.1 Human health risk assessment (non-carcinogenic risk)*

The soil heavy metals contamination levels and ecological risk were evaluated using the various indices.

##### *2.5.1.1 Hazard quotient (HQ)*

The HQ for non-carcinogenic risk was calculated using the equation by USEPA (1999)

$$HQ = \frac{CDI}{RfD} \text{ ---------- (27)}$$

where CDI is the daily dose of heavy metals (mg/L) to which consumers might be exposed and RfD is the reference dose which is the daily dosage that enable individual to sustain this level of exposure over a long period of time without experiencing any harmful effects.

If HQ > 1, it represents adverse non-carcinogenic effects of concern, while HQ < 1 represents acceptable level.

*2.5.1.2 Hazard index*

Since more than one toxicant is present, the interactions are considered. The toxic risks due to potentially hazardous substances present in the same media are assumed to be additive.

The HQs may then be summed to arrive at the overall toxic risk.

$HI = \sum_{i-1}^{n}(HQ)i$ ---------- (4)

where;
HI is the hazard index for the overall toxic risk
n is the total number of metals under consideration.
HI <1 indicates no adverse health effects, whereas HI > 1 indicates the possible health effects.

*2.5.1.3 Carcinogenic risk*

Cancer risk is the hazard from a lifetime average dose exposure to 1 mg/kg body weight/day of a pollutant. Cancer risk assessment is the probability that one may develop cancer over a 70-year lifetime due to a 24-hour exposure to a potential carcinogen (Adamu *et al.,* 2015). Cancer risk was calculated as the product of CDI (mg/kg/day) and cancer slope factor (CSF) measured in (mg/kg/day)

$CR = CDI \,.\, CSF$ ---------- (5)

Where:
CR is the Cancer Risk
CDI is the Chronic daily intake (mg/ kg/BW/day)
CSF is the Cancer Slope Factor

## *2.6 Ecological assessment*

The soil heavy metals contamination levels and ecological risks were evaluated using the various indices.

*2.6.1 Geoaccumulation Index (Igeo)*
The following equation was used to calculate the geoaccumulation index (Igeo):

$I_{geo} = Log_2[(Cn)/1.5(Bn)]$ ----------(6)

where,
"Cn" represents heavy metal (n) concentration in the sample
"Bn" represents heavy metal (n) concentration in the geochemical background
"1.5" represents the background matrix correction due to lithogenic effects.

*2.6.2 Contamination factor (CF)*

The contamination factor (CF) was used to evaluate heavy metal contamination.

$$CF = (C_0/C_n) \text{ ----------(7)}$$

where,
$C_n$ represents the concentration of each element
$C_0$ is the average concentration of each element

*2.6.3 Ecological risk assessment*

In this study, the following relationships were used to assess the ecological risk and environmental risk potential (RI) of coastal soils of the wetland.

$$\sum_{i=1}^{n} E_i \text{ ----------(8)}$$

$$ERI = TR \times CF \text{ ----------(9)}$$

Where,
CF is the Contamination factor
ER indicates the ecological risk of each element studied
RI represents the sum of the elements
$E_i$ is the monomial potential ecological risk factor.
The value of TR indicates the toxicity of heavy metals

*2.6.4 Enrichment factor*

The determination of the EF indicates the level of contamination of metals in the soil, which is a useful index for separating the natural and human sources of metals from each The EF for each metal will be calculated based on the ratio between the normalized element and the background value of the elements.

$$EF = (Cx_{metal}/Fe)sample \div (Cref_{metal}/Fe)Background \text{ ----------(10)}$$

Where,
*Cref* is the concentration of the reference element in the sample
Cx is the concentration of the element considered in the sample.

### *2.7 Statistical analysis*

The statistical Analysis of variance (ANOVA) was used to test whether or not significant differences existed between the sites. The threshold for statistical significance was set at 0.05.

## 3. Results

### *3.1 Physicochemical Parameters*

**Table 1.** Physicochemical Parameters

| S/N | Location | pH | Electrical Conductivity ($\mu$S/cm) | Cation Exchange Capacity (cmol/Kg) |
|---|---|---|---|---|
| 1. | Rice Mill | 6.8±0.01 | 45.6±0.00 | 8745 |
| 2. | Industrial Layout | 6.7±0.00 | 43.5±0.01 | 7021 |
| 3. | Teaching Hospital | 6.6±0.01 | 68.2±0.01 | 12608 |
| 4. | Apir | 6.9±0.01 | 46.8±0.01 | 10864 |
| 5. | North Bank | 6.7±0.01 | 49.0±0.00 | 18771 |

### *3.2: Concentrations of Heavy Metals*

**Table 2:** Result of Selected Heavy Metals Concentrations of Soil Samples

| S/N | Heavy Metals | Rice Mill | Industrial Layout | Teaching Hospital | Apir Mechanic Workshop | North Bank | Control | WHO, (Mg/Kg) | WSRA (Mg/Kg) |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Fe | 0.167 | 0.277 | 0.263 | 0.183 | 3.16 | 0.000 | 5000 | 300 |
| 2. | Zn | 0.136 | 0.115 | 0.157 | 0.248 | 0.038 | 0.000 | 300 | 127 |
| 3. | Ni | 0.128 | 0.123 | 0.167 | 0.192 | 0.116 | 0.000 | 35 | 50 |
| 4. | Pb | 18.7 | 0.795 | 19.3 | 45.7 | 31.6 | 0.000 | 100 | 16 |
| 5. | Cu | 0.236 | 0.333 | 0.360 | 0.336 | 0.506 | 0.000 | 100 | 32 |

### *3.3 Geoaccumulation Index*

**Table 3:** Geoaccumulation Index ($I_{geo}$) of heavy metals in Soil Samples

| S/N | Heavy Metals | Rice Mill | Industrial Layout | Teaching Hospital | Apir Mechanic Workshop | North Bank |
|---|---|---|---|---|---|---|
| 1. | Fe | -11.4 | -10.7 | -10.8 | -11.3 | -7.15 |
| 2. | Zn | -10.5 | -10.7 | -10.2 | -9.59 | -12.3 |
| 3. | Ni | -9.20 | -9.25 | -8.81 | -8.61 | -9.33 |
| 4. | Pb | -0.360 | -4.92 | -0.315 | 0.926 | 0.401 |
| 5. | Cu | -7.67 | -7.17 | -7.06 | -7.16 | -6.51 |

### *3.4 Contamination Factor (CF)*

**Table 4:** Contamination Factor (CF) of heavy metals in Soil Samples

| S/N | Heavy Metals | Rice Mill | Industrial Layout | Teaching Hospital | Apir Mechanic Workshop | North Bank |
|---|---|---|---|---|---|---|
| 1. | Fe | $5.57\times10^{-4}$ | $9.23\times10^{-4}$ | $8.77\times10^{-4}$ | $6.10\times10^{-4}$ | 0.011 |
| 2. | Zn | $1.07\times10^{-3}$ | $9.06\times10^{-4}$ | $1.24\times10^{-3}$ | $1.95\times10^{-3}$ | $2.99\times10^{-4}$ |
| 3. | Ni | $2.56\times10^{-3}$ | $2.46\times10^{-3}$ | $3.34\times10^{-3}$ | $3.84\times10^{-3}$ | $2.32\times10^{-3}$ |
| 4. | Pb | 1.17 | 0.049 | 1.21 | 2.86 | 1.98 |
| 5. | Cu | $7.38\times10^{-3}$ | 0.010 | 0.011 | 0.011 | 0.016 |

### *3.5 Enrichment Factor (EF)*

**Table 5:** Enrichment Factor (EF) of heavy metals in Soil Samples

| S/N | Heavy Metals | Rice Mill | Industrial Layout | Teaching Hospital | Apir Mechanic Workshop | North Bank |
|---|---|---|---|---|---|---|
| 1. | Zn | 1.92 | 0.981 | 1.41 | 3.22 | 0.026 |
| 2. | Ni | 4.59 | 2.66 | 3.80 | 6.29 | 0.222 |
| 3. | Pb | 2113 | 54.2 | 1385 | 4717 | 189 |
| 4. | Cu | 13.2 | 11.2 | 12.8 | 17.2 | 1.49 |

### *3.6 Ecological risk Index (ERI)*

**Table 6:** Ecological risk Index (ERI) of heavy metals in Soil Samples

| S/N | Heavy Metals | Rice Mill | Industrial Layout | Teaching Hospital | Apir Mechanic Workshop | North Bank |
|---|---|---|---|---|---|---|
| 1. | Fe | $5.57\times10^{-4}$ | $9.23\times10^{-4}$ | $8.77\times10^{-4}$ | $6.10\times10^{-4}$ | 0.011 |
| 2. | Zn | $1.07\times10^{-3}$ | $9.06\times10^{-4}$ | $1.24\times10^{-3}$ | $1.95\times10^{-3}$ | $2.99\times10^{-4}$ |
| 3. | Ni | 0.013 | 0.012 | 0.017 | 0.019 | 0.012 |
| 4. | Pb | 5.85 | 0.245 | 6.05 | 14.3 | 9.90 |
| 5. | Cu | 0.037 | 0.050 | 0.055 | 0.055 | 0.080 |
| 6. | $R_1$ | 5.90 | 0.309 | 6.12 | 14.4 | 10.0 |

### *3.7 Assessment of Human Health Risk Assessment*

**Table 7**: Chronic Daily Intake (CDI) of Selected Heavy Metals in Soil Samples

| | | Chronic Daily Intake (CDI) | | | | | |
|---|---|---|---|---|---|---|---|
| Sample Site | Pathways | Recipients | Fe | Zn | Ni | Pb | Cu |
| Rice Mill | Ingestion | Children | $2.16\times10^{-6}$ | $1.74\times10^{-6}$ | $1.64\times10^{-6}$ | $2.39\times10^{-4}$ | $3.02\times10^{-6}$ |
| | | Adult | $2.29\times10^{-7}$ | $1.86\times10^{-7}$ | $1.75\times10^{-7}$ | $2.56\times10^{-5}$ | $3.23\times10^{-7}$ |
| | Dermal | Children | $7.17\times10^{-10}$ | $5.85\times10^{-9}$ | $2.19\times10^{-9}$ | $8.03\times10^{-8}$ | $1.01\times10^{-9}$ |
| | | Adult | $1.81\times10^{-10}$ | $8.85\times10^{-10}$ | $5.55\times10^{-10}$ | $2.02\times10^{-8}$ | $2.56\times10^{-10}$ |
| | Inhalation | Children | $8.11\times10^{-11}$ | $6.61\times10^{-11}$ | $6.23\times10^{-11}$ | $9.08\times10^{-9}$ | $1.15\times10^{-10}$ |
| | | Adult | $3.48\times10^{-11}$ | $2.83\times10^{-11}$ | $2.66\times10^{-11}$ | $3.89\times10^{-9}$ | $4.91\times10^{-11}$ |
| Industrial Layout | Ingestion | Children | $3.54\times10^{-6}$ | $1.47\times10^{-6}$ | $1.57\times10^{-6}$ | $1.02\times10^{-5}$ | $4.26\times10^{-6}$ |
| | | Adult | $3.79\times10^{-7}$ | $1.56\times10^{-7}$ | $1.56\times10^{-7}$ | $1.09\times10^{-6}$ | $4.56\times10^{-7}$ |
| | Dermal | Children | $1.19\times10^{-9}$ | $2.96\times10^{-9}$ | $2.11\times10^{-9}$ | $1.47\times10^{-8}$ | $1.43\times10^{-9}$ |
| | | Adult | $3.01\times10^{-10}$ | $7.48\times10^{-10}$ | $5.34\times10^{-10}$ | $9.34\times10^{-10}$ | $3.61\times10^{-}$ |
| | Inhalation | Children | $1.35\times10^{-10}$ | $5.58\times10^{-11}$ | $5.97\times10^{-11}$ | $3.86\times10^{-10}$ | $1.62\times10^{-10}$ |
| | | Adult | $5.77\times10^{-11}$ | $2.39\times10^{-11}$ | $2.56\times10^{-11}$ | $1.66\times10^{-10}$ | $6.93\times10^{-11}$ |
| Teaching Hospital | Ingestion | Children | $3.36\times10^{-6}$ | $2.01\times10^{-6}$ | $2.14\times10^{-6}$ | $2.48\times10^{-4}$ | $4.58\times10^{-6}$ |
| | | Adult | $3.60\times10^{-7}$ | $2.15\times10^{-7}$ | $2.29\times10^{-7}$ | $2.64\times10^{-5}$ | $4.90\times10^{-7}$ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Dermal | Children | $1.13\times10^{-9}$ | $4.05\times10^{-9}$ | $2.87\times10^{-9}$ | $8.29\times10^{-8}$ | $1.54\times10^{-9}$ |
| | | Adult | $2.85\times10^{-10}$ | $1.02\times10^{-9}$ | $7.25\times10^{-10}$ | $2.09\times10^{-8}$ | $3.88\times10^{-10}$ |
| | Inhalation | Children | $1.28\times10^{-10}$ | $7.63\times10^{-11}$ | $8.11\times10^{-11}$ | $9.38\times10^{-9}$ | $7.45\times10^{-11}$ |
| | | Adult | $5.48\times10^{-11}$ | $3.27\times10^{-11}$ | $3.48\times10^{-11}$ | $4.02\times10^{-9}$ | $2.74\times10^{-11}$ |
| Apir Mechanic Workshop | Ingestion | Children | $2.34\times10^{-6}$ | $3.17\times10^{-6}$ | $2.45\times10^{-6}$ | $5.84\times10^{-4}$ | $4.29\times10^{-6}$ |
| | | Adult | $2.51\times10^{-7}$ | $3.39\times10^{-7}$ | $2.63\times10^{-7}$ | $6.26\times10^{-5}$ | $4.60\times10^{-7}$ |
| | Dermal | Children | $7.86\times10^{-10}$ | $6.39\times10^{-9}$ | $3.29\times10^{-9}$ | $1.96\times10^{-7}$ | $1.44\times10^{-9}$ |
| | | Adult | $1.99\times10^{-10}$ | $1.61\times10^{-9}$ | $8.33\times10^{-10}$ | $4.96\times10^{-8}$ | $3.65\times10^{-10}$ |
| | Inhalation | Children | $8.89\times10^{-11}$ | $1.20\times10^{-10}$ | $9.33\times10^{-11}$ | $2.22\times10^{-8}$ | $1.63\times10^{-10}$ |
| | | Adult | $3.81\times10^{-11}$ | $5.16\times10^{-11}$ | $3.99\times10^{-11}$ | $9.51\times10^{-9}$ | $6.99\times10^{-11}$ |
| North Bank | Ingestion | Children | $4.04\times10^{-5}$ | $4.85\times10^{-7}$ | $1.48\times10^{-6}$ | $4.04\times10^{-4}$ | $6.47\times10^{-6}$ |
| | | Adult | $4.33\times10^{-6}$ | $5.20\times10^{-8}$ | $1.59\times10^{-7}$ | $4.33\times10^{-5}$ | $6.93\times10^{-7}$ |
| | Dermal | Children | $1.36\times10^{-8}$ | $9.79\times10^{-10}$ | $1.99\times10^{-9}$ | $1.36\times10^{-7}$ | $2.17\times10^{-9}$ |
| | | Adult | $3.43\times10^{-9}$ | $2.47\times10^{-10}$ | $5.03\times10^{-10}$ | $3.43\times10^{-8}$ | $5.49\times10^{-7}$ |
| | Inhalation | Children | $1.54\times10^{-9}$ | $1.85\times10^{-11}$ | $5.63\times10^{-11}$ | $1.54\times10^{-8}$ | $2.46\times10^{-10}$ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Adult | $6.58\times10^{-10}$ | $7.86\times10^{-11}$ | $2.41\times10^{-11}$ | $6.58\times10^{-9}$ | $1.05\times10^{-10}$ |

### *3.8 Hazard Quotient (HQ)*

**Table 8:** Hazard Quotient (HQ) of Selected Heavy Metals in Soil Samples

| | | | Hazard Quotient (HQ) | | | | |
|---|---|---|---|---|---|---|---|
| Sample Site | Pathways | Recipients | Fe | Zn | Ni | Pb | Cu |
| Rice Mill | Ingestion | Children | $3.06\times10^{-6}$ | $5.80\times10^{-6}$ | $8.20\times10^{-5}$ | $6.80\times10^{-2}$ | $7.35\times10^{-5}$ |
| | | Adult | $3.27\times10^{-7}$ | $6.20\times10^{-7}$ | $8.75\times10^{-6}$ | $7.31\times10^{-3}$ | $8.06\times10^{-6}$ |
| | Dermal | Children | $5.12\times10^{-9}$ | $5.85\times10^{-8}$ | $4.01\times10^{-7}$ | $1.55\times10^{-4}$ | $8.41\times10^{-8}$ |
| | | Adult | $2.26\times10^{-10}$ | $1.48\times10^{-8}$ | $1,03\times10^{-7}$ | $3.85\times10^{-5}$ | $2.13\times10^{-8}$ |
| | Inhalation | Children | $1.16\times10^{-10}$ | $2.20\times10^{-10}$ | $3.02\times10^{-9}$ | $2.57\times10^{-6}$ | $3.73\times10^{-9}$ |
| | | Adult | $4.97\times10^{-11}$ | $9.43\times10^{-11}$ | $1.29\times10^{-9}$ | $1.10\times10^{-6}$ | $1.22\times10^{-9}$ |
| Industrial Layout | Ingestion | Children | $5.06\times10^{-6}$ | $4.90\times10^{-6}$ | $7.85\times10^{-5}$ | $2.91\times10^{-3}$ | $1.07\times10^{-4}$ |
| | | Adult | $5.41\times10^{-7}$ | $5.20\times10^{-7}$ | $7.86\times10^{-7}$ | $3.11\times10^{-4}$ | $1.14\times10^{-5}$ |
| | Dermal | Children | $8.50\times10^{-9}$ | $4.90\times10^{-8}$ | $3.91\times10^{-7}$ | $2.80\times10^{-5}$ | $1.19\times10^{-7}$ |
| | | Adult | $2.15\times10^{-9}$ | $1.25\times10^{-8}$ | $9.89\times10^{-8}$ | $1.78\times10^{-6}$ | $2.63\times10^{-8}$ |
| | Inhalation | Children | $1.93\times10^{-10}$ | $1.86\times10^{-10}$ | $2.89\times10^{-9}$ | $1.09\times10^{-7}$ | $4.03\times10^{-9}$ |
| | | Adult | $8.24\times10^{-11}$ | $7.97\times10^{-11}$ | $1.24\times10^{-9}$ | $4.70\times10^{-8}$ | $1.72\times10^{-9}$ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Teaching Hospital | Ingestion | Children | $4.80\times10^{-6}$ | $6.70\times10^{-6}$ | $1.07\times10^{-4}$ | 0.071 | $1.15\times10^{-4}$ |
| | | Adult | $5.14\times10^{-7}$ | $7.17\times10^{-7}$ | $1.15\times10^{-5}$ | $7.54\times10^{-3}$ | $1.23\times10^{-5}$ |
| | Dermal | Children | $8.07\times10^{-9}$ | $6.75\times10^{-8}$ | $5.31\times10^{-7}$ | $1.57\times10^{-4}$ | $1.28\times10^{-7}$ |
| | | Adult | $2.04\times10^{-7}$ | $1.70\times10^{-8}$ | $1.34\times10^{-7}$ | $3.98\times10^{-5}$ | $3.23\times10^{-8}$ |
| | Inhalation | Children | $1.83\times10^{-10}$ | $2.54\times10^{-10}$ | $3.94\times10^{-9}$ | $2.66\times10^{-6}$ | $1.85\times10^{-9}$ |
| | | Adult | $7.83\times10^{-11}$ | $1.09\times10^{-10}$ | $1.69\times10^{-9}$ | $1.14\times10^{-6}$ | $6.82\times10^{-10}$ |
| Apir Mechanic Workshop | Ingestion | Children | $3.34\times10^{-6}$ | $1.06\times10^{-5}$ | $1.23\times10^{-4}$ | 0.167 | $1.07\times10^{-4}$ |
| | | Adult | $3.59\times10^{-7}$ | $1.13\times10^{-6}$ | $1.34\times10^{-5}$ | $1.80\times10^{-2}$ | $1.15\times10^{-5}$ |
| | Dermal | Children | $5.61\times10^{-9}$ | $1.07\times10^{-7}$ | $6.09\times10^{-7}$ | $3.73\times10^{-4}$ | $1.20\times10^{-7}$ |
| | | Adult | $1.42\times10^{-9}$ | $2.68\times10^{-8}$ | $1.54\times10^{-7}$ | $9.45\times10^{-5}$ | $3.04\times10^{-8}$ |
| | Inhalation | Children | $1.27\times10^{-10}$ | $2.0\times10^{-9}$ | $4.67\times10^{-9}$ | $6.29\times10^{-6}$ | $4.05\times10^{-9}$ |
| | | Adult | $5.44\times10^{-11}$ | $8.60\times10^{-10}$ | $1.94\times10^{-9}$ | $2.69\times10^{-6}$ | $1.74\times10^{-9}$ |
| North Bank | Ingestion | Children | $5.77\times10^{-5}$ | $1.62\times10^{-6}$ | $7.40\times10^{-5}$ | 0.115 | $1.62\times10^{-4}$ |
| | | Adult | $6.19\times10^{-6}$ | $1.73\times10^{-7}$ | $7.95\times10^{-6}$ | 0.124 | $1.73\times10^{-5}$ |
| | Dermal | Children | $9.71\times10^{-8}$ | $1.63\times10^{-8}$ | $3.69\times10^{-7}$ | $2.59\times10^{-4}$ | $1.81\times10^{-7}$ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Adult | $2.45\times10^{-8}$ | $4.17\times10^{-9}$ | $9.31\times10^{-8}$ | $6.53\times10^{-5}$ | $4.58\times10^{-5}$ |
| | Inhalation | Children | $2.20\times10^{-9}$ | $6.17\times10^{-11}$ | $2.73\times10^{-9}$ | $4.36\times10^{-6}$ | $6.12\times10^{-9}$ |
| | | Adult | $9.40\times10^{-10}$ | $2.62\times10^{-10}$ | $1.17\times10^{-9}$ | $1.86\times10^{-6}$ | $2.61\times10^{-9}$ |

### *3.9. Hazard Index*

**Table 11:** Hazard Index values of Selected Heavy Metals in Soil Samples

| | | | Hazard Index | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample Site | Pathways | Recipients | Fe | Zn | Ni | Pb | Cu | Total |
| Rice Mill | Ingestion | Children | $3.06\times10^{-6}$ | $5.80\times10^{-6}$ | $8.20\times10^{-5}$ | $6.80\times10^{-2}$ | $7.35\times10^{-5}$ | $6.82\times10^{-2}$ |
| | | Adult | $3.27\times10^{-7}$ | $6.20\times10^{-7}$ | $8.75\times10^{-6}$ | $7.31\times10^{-3}$ | $8.06\times10^{-6}$ | $7.37\times10^{-3}$ |
| | Dermal | Children | $5.12\times10^{-9}$ | $5.85\times10^{-8}$ | $4.01\times10^{-7}$ | $1.55\times10^{-4}$ | $8.41\times10^{-8}$ | $1.56\times10^{-4}$ |
| | | Adult | $2.26\times10^{-10}$ | $1.48\times10^{-8}$ | $1,03\times10^{-7}$ | $3.85\times10^{-5}$ | $2.13\times10^{-8}$ | $3.12\times10^{-4}$ |
| | Inhalation | Children | $1.16\times10^{-10}$ | $2.20\times10^{-10}$ | $3.02\times10^{-9}$ | $2.57\times10^{-6}$ | $3.73\times10^{-9}$ | $2.58\times10^{-6}$ |
| | | Adult | $4.97\times10^{-11}$ | $9.43\times10^{-11}$ | $1.29\times10^{-9}$ | $1.10\times10^{-6}$ | $1.22\times10^{-9}$ | $1.10\times10^{-6}$ |
| Industrial Layout | Ingestion | Children | $5.06\times10^{-6}$ | $4.90\times10^{-6}$ | $7.85\times10^{-5}$ | $2.91\times10^{-3}$ | $1.07\times10^{-4}$ | $3.11\times10^{-3}$ |
| | | Adult | $5.41\times10^{-7}$ | $5.20\times10^{-7}$ | $7.86\times10^{-7}$ | $3.11\times10^{-4}$ | $1.14\times10^{-5}$ | $3.24\times10^{-4}$ |
| | Dermal | Children | $8.50\times10^{-9}$ | $4.90\times10^{-8}$ | $3.91\times10^{-7}$ | $2.80\times10^{-5}$ | $1.19\times10^{-7}$ | $2.86\times10^{-5}$ |
| | | Adult | $2.15\times10^{-9}$ | $1.25\times10^{-8}$ | $9.89\times10^{-8}$ | $1.78\times10^{-6}$ | $2.63\times10^{-8}$ | $1.92\times10^{-6}$ |
| | Inhalation | Children | $1.93\times10^{-10}$ | $1.86\times10^{-10}$ | $2.89\times10^{-9}$ | $1.09\times10^{-7}$ | $4.03\times10^{-9}$ | $1.16\times10^{-7}$ |
| | | Adult | $8.24\times10^{-11}$ | $7.97\times10^{-11}$ | $1.24\times10^{-9}$ | $4.70\times10^{-8}$ | $1.72\times10^{-9}$ | $5.01\times10^{-8}$ |
| Teaching Hospital | Ingestion | Children | $4.80\times10^{-6}$ | $6.70\times10^{-6}$ | $1.07\times10^{-4}$ | $7.10\times10^{-2}$ | $1.15\times10^{-4}$ | $7.12\times10^{-2}$ |
| | | Adult | $5.14\times10^{-7}$ | $7.17\times10^{-7}$ | $1.15\times10^{-5}$ | $7.54\times10^{-3}$ | $1.23\times10^{-5}$ | $7.57\times10^{-3}$ |
| | Dermal | Children | $8.07\times10^{-9}$ | $6.75\times10^{-8}$ | $5.31\times10^{-7}$ | $1.57\times10^{-4}$ | $1.28\times10^{-7}$ | $1.58\times10^{-4}$ |
| | | Adult | $2.04\times10^{-7}$ | $1.70\times10^{-8}$ | $1.34\times10^{-7}$ | $3.98\times10^{-5}$ | $3.23\times10^{-8}$ | $4.02\times10^{-5}$ |
| | Inhalation | Children | $1.83\times10^{-10}$ | $2.54\times10^{-10}$ | $3.94\times10^{-9}$ | $2.66\times10^{-6}$ | $1.85\times10^{-9}$ | $2.67\times10^{-6}$ |
| | | Adult | $7.83\times10^{-11}$ | $1.09\times10^{-}$ | $1.69\times10^{-9}$ | $1.14\times10^{-6}$ | $6.82\times10^{-}$ | $1.14\times10^{-4}$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | $10^{-10}$ | | | $10^{-10}$ | |
| Apir Mechanic Workshop | Ingestion | Children | $3.34\times10^{-6}$ | $1.06\times10^{-5}$ | $1.23\times10^{-4}$ | 0.167 | $1.07\times10^{-4}$ | 0.167 |
| | | Adult | $3.59\times10^{-7}$ | $1.13\times10^{-6}$ | $1.34\times10^{-5}$ | $1.80\times10^{-2}$ | $1.15\times10^{-5}$ | $1.80\times10^{-2}$ |
| | Dermal | Children | $5.61\times10^{-9}$ | $1.07\times10^{-7}$ | $6.09\times10^{-7}$ | $3.73\times10^{-4}$ | $1.20\times10^{-7}$ | $3.74\times10^{-4}$ |
| | | Adult | $1.42\times10^{-9}$ | $2.68\times10^{-8}$ | $1.54\times10^{-7}$ | $9.45\times10^{-5}$ | $3.04\times10^{-8}$ | $9.47\times10^{-5}$ |
| | Inhalation | Children | $1.27\times10^{-10}$ | $2.00\times10^{-9}$ | $4.67\times10^{-9}$ | $6.29\times10^{-6}$ | $4.05\times10^{-9}$ | $6.30\times10^{-6}$ |
| | | Adult | $5.44\times10^{-11}$ | $8.60\times10^{-10}$ | $1.94\times10^{-9}$ | $2.69\times10^{-6}$ | $1.74\times10^{-9}$ | $2.69\times10^{-6}$ |
| North Bank | Ingestion | Children | $5.77\times10^{-5}$ | $1.62\times10^{-6}$ | $7.40\times10^{-5}$ | 0.115 | $1.62\times10^{-4}$ | 0.115 |
| | | Adult | $6.19\times10^{-6}$ | $1.73\times10^{-7}$ | $7.95\times10^{-6}$ | 0.124 | $1.73\times10^{-5}$ | 0.124 |
| | Dermal | Children | $9.71\times10^{-8}$ | $1.63\times10^{-8}$ | $3.69\times10^{-7}$ | $2.59\times10^{-4}$ | $1.81\times10^{-7}$ | $2.59\times10^{-4}$ |
| | | Adult | $2.45\times10^{-8}$ | $4.17\times10^{-9}$ | $9.31\times10^{-8}$ | $6.53\times10^{-5}$ | $4.58\times10^{-5}$ | $1.11\times10^{-4}$ |
| | Inhalation | Children | $2.20\times10^{-9}$ | $6.17\times10^{-11}$ | $2.73\times10^{-9}$ | $4.36\times10^{-6}$ | $6.12\times10^{-9}$ | $4.37\times10^{-6}$ |
| | | Adult | $9.40\times10^{-10}$ | $2.62\times10^{-10}$ | $1.17\times10^{-9}$ | $1.86\times10^{-6}$ | $2.61\times10^{-9}$ | $1.86\times10^{-6}$ |

### *3.10 Carcinogenic Risk Assessment*

**Table 12:** Carcinogenic Risk Assessment of Selected Heavy Metals in Soil Samples

| | | Carcinogenic Risk Assessment | | |
|---|---|---|---|---|
| Sample Site | Pathways | Recipients | Ni | Pb |
| Rice Mill | Ingestion | Children | $2.38\times10^{-7}$ | $1.74\times10^{-7}$ |
| | | Adult | $1.06\times10^{-7}$ | $7.78\times10^{-8}$ |
| | Dermal | Children | $172\times10^{-8}$ | $5.86\times10^{-10}$ |
| | | Adult | $1.80\times10^{-7}$ | $8.52\times10^{-8}$ |
| | Inhalation | Children | $4.85\times10^{-12}$ | $3.27\times10^{-11}$ |
| | | Adult | $8.67\times10^{-12}$ | $5.83\times10^{-11}$ |
| Industrial Layout | Ingestion | Children | $2.29\times10^{-7}$ | $7.40\times10^{-9}$ |

| | | | | |
|---|---|---|---|---|
| | | Adult | $1.02\times10^{-7}$ | $3.31\times10^{-9}$ |
| | Dermal | Children | $1.52\times10^{-10}$ | $2.49\times10^{-11}$ |
| | | Adult | $1.60\times10^{-10}$ | $2.62\times10^{-11}$ |
| | Inhalation | Children | $4.66\times10^{-12}$ | $1.39\times10^{-12}$ |
| | | Adult | $8.34\times10^{-12}$ | $2.48\times10^{-12}$ |
| Teaching Hospital | Ingestion | Children | $3.11\times10^{-7}$ | $1.80\times10^{-7}$ |
| | | Adult | $1.39\times10^{-7}$ | $8.02\times10^{-8}$ |
| | Dermal | Children | $1.07\times10^{-10}$ | $6.04\times10^{-10}$ |
| | | Adult | $2.18\times10^{-10}$ | $6.36\times10^{-10}$ |
| | Inhalation | Children | $6.32\times10^{-12}$ | $3.38\times10^{-11}$ |
| | | Adult | $1.13\times10^{-11}$ | $6.05\times10^{-11}$ |
| Apir Mechanic Workshop | Ingestion | Children | $3.57\times10^{-7}$ | $4.26\times10^{-7}$ |
| | | Adult | $1.59\times10^{-7}$ | $1.90\times10^{-7}$ |
| | Dermal | Children | $2.38\times10^{-10}$ | $1.43\times10^{-9}$ |
| | | Adult | $2.49\times10^{-10}$ | $1.50\times10^{-9}$ |
| | Inhalation | Children | $7.27\times10^{-12}$ | $7.98\times10^{-11}$ |
| | | Adult | $1.30\times10^{-11}$ | $1.43\times10^{-10}$ |
| North Bank | Ingestion | Children | $1.08\times10^{-7}$ | $2.94\times10^{-7}$ |
| | | Adult | $9.66\times10^{-8}$ | $1.32\times10^{-7}$ |
| | Dermal | Children | $1.44\times10^{-10}$ | $9.86\times10^{-10}$ |
| | | Adult | $1.50\times10^{-10}$ | $1.04\times10^{-9}$ |
| | Inhalation | Children | $4.39\times10^{-12}$ | $1.20\times10^{-9}$ |
| | | Adult | $7.86\times10^{-12}$ | $2.14\times10^{-9}$ |

## 4. Discussion

### *4.1 Physicochemical Parameters*

#### *4.1.1 The pH*

The physicochemical properties of the soil is presented in Tables 3. The pH values of soil samples ranged from 6.6± 0.01 to 6.9± 0.01 in all sampling sites, indicating that the analyzed soil is slightly acidic to slightly alkaline. The pH obtained from this study will support the availability of certain plant nutrients in the soil. All the samples pH values were within the WHO permissible limits of of 6.5–8.5 for drinking water. Hence, this pH will play a pivotal role in determining the solubility and accessibility of nutrients and metals in the soil, thereby influencing plant growth and development. These results were consistent with findings reported by previous studies (Charity et al., 2018; Onwukeme and Okechukwu, 2021). It also contradicts some results of Akodu et al., (2023) who reported a range of 5.05 ±0.03- 7.12 ± 0.02 in the Assessment of Physicochemical Properties of some Cultivated Floodplains in Ekiti State, Southwest Nigeria and this could be as a result of differences in geographical settings.

#### *4.1.2 Electrical Conductivity*

The electrical conductivity (µScm) from this work ranges from 43.5± 0.01 to 68.2± 0.01 µScm with the highest recorded in the sample collected from the Teaching Hospital probably due nature of contaminants deposited on the soil around the vicinity of the hospital. The values obtained in this study were higher than those reported by Egbenda et al. (2015) who reported a range of 10-20 µS/cm for agricultural soils of Sierra Rutile environ of Sierra Leone. But lower than that reported by Akpoveta et al. (2014) who reported 140.8 µS/cm for Onitsha flooded soil, Anambra State, and 112.8 µS/cm for Asaba floodplain in Delta State, Nigeria. This variation may perhaps be attributed to differences in ecozones. The electrical conductivity less than 1000 µS/cm is graded as normal for plant growth, 1000-2000 µS/cm as critical for germination, 2000-3000 µS/cm critical for growth of salt sensitive crop and >3000 µS/cm is graded as injurious to crops (Horneck et al., 2011). Hence, the range of EC values obtained from this study is good for plant growth.

#### *4.1.3 Cation Exchange Capacity*

Cation exchange capacity (CEC) refers to the ability of dust particles to hold positively charged ions, which can impact the retention of both nutrients and pollutants [35]. The results of CEC obtained in this study range from 15.0 to 9460 mg/Kg-1 with the highest value recorded in Quality Control while the lowest value was recorded in Civil sections as depicted in Table 4.

### *4.2 Concentration of Heavy Metals*

The concentrations of heavy metals (Fe, Zn, Ni, Pb, Cu) obtained from Surface Soils in Makurdi Metropolis are presented in Tables 4.

#### *4.2.1 Iron (Fe)*

The concentrations of Fe in the soil examined ranged from 0.167 to 3.16 mg/kg. Despite the essential role of Fe in the body's growth and development processes, the average falls well below the WHO. Iron is crucial for

proteins like myoglobin and hemoglobin, facilitating oxygen distribution in the body. This result disagree with the previous work by Ayaz et al., (2023) who reported high level of Fe in Comprehensive human health risk assessment of heavy metal contamination in urban soils: insights from selected metropolitan zones in Karachi, Pakistan.

*4.2.2 Zinc (Zn)*

Zn concentrations in all the studied sites range from 0.038 to 0.248 mg/kg with the highest concentration recorded in Apir Mechanic Workshop and the lowest concentration observed in North Bank and the results are below the permissible limit of WHO (0.30 mg/kg). This result indicates that, the soils in the study sites were not contamination with Zn. This result differs with the previous work reported by Lala et al., (2022) on Assessment of Heavy Metal Pollution Status in Surface Soil of a Nigerian University, who reported a concentration of 0.36 mg/g). The differences could be attributed to the effects from different human activities or the high nature of the corresponding natural background value.

*4.2.3 Nickel (Ni)*

Values for Ni (mg/kg) were in the range 0.116 to 0.192. The concentration of Ni was highest Apir Mechanic Workshop soil samples and lowest in the North bank soil samples. Ni concentration in this study contradicts with the value reported by Ande *et al*. (2017) who reported high concentration of Ni for Wurukun abattoir soil.

*4.2.4 Lead (Pb)*

The concentrations of Pb in the studied sites range from 0.795 to 45.7 mg/kg with the highest concentration recorded in Apir Mechanic Workshop and the lowest concentration in Industrial Layout. These values were notably higher than the WHO permissible limit. The higher Pb level in the study was suggested to have been influenced by traffic volume and exhaust from motor vehicles. This is similar to the result obtained for a study carried out by a group of researchers in Ilorin, Nigeria (Okoro *et al,* 2016). Again, the high concentration of Pb in Apir Mechanic Workshop, North Bank, Teaching Hospital and Rice mill can be characterized by high automobiles and power generating sets and other trace metals such as Mn, Cu, Cr and Zn are also reported as additives in lubricants and gasoline. As observed by (Ololade, 2014). These metals are also (Pb, Cu and Zn) are reported to be present in vehicular emissions, tires, wires, alloys, brake parts, etc. (Raj and Ram, 2013; Ngole-Jeme *et al.,* (2015).

*4.2.5 Copper (Cu)*

The concentrations of cu in the sample sites varied between 0.236 and 0.506 mg/kg. These were all higher than the permissible limit of WHO (0.10 mg/Kg) and may be attributed to the higher natural background value and probably electrical and electronic parts of automobile wastes and alloys from corroding metal parts that have possibly leached into the soil of these various sites resulting to high Cu present as previously reported by (Nwachukwu *et al.,* 2011). This study is also consistent with that of Lala *et al.,* (2022), who also reported high concentration of Cu in the Assessment of Heavy Metal Pollution Status in Surface Soil of a Nigerian University. Generally, the results showed that the relative abundance of heavy metals across the locations were in the order Pb > Fe > Cu > Zn > Ni

### *4.3 Assessment of Ecological Risk*

#### *4.3.1 Geoaccumulation index ($I_{geo}$)*

The Igeo index was considered to estimate the soil contamination level from the study sites and is presented in Table 5. The result shows that, the Igeo of all the selected metals in the study soils were unpolluted suggesting that soils in the sample areas have natural background levels for these metals excerpt Pb in Apir Mechanic Workshop (0.926) and North Bank (0.401) that indicate moderately polluted level. This finding is consistent with the previous work reported by Lala *et al.,* (2022) on Assessment of Heavy Metal Pollution Status in Surface Soil of a Nigerian University.

#### *4.3.2 Contamination factor*

The contamination factor ($C_f$) of the elements are presented in Table 6. The contamination factor ($C_f$) of the elements in all the sampling sites were below 1 indicating low contamination of the studied soil excerpt Pb in Rice Mill, Teaching Hospital, Apir Mechanic Workshop and North Bank sites having showing moderate contamination. This is probably due to human activities been carried out the various sampling sites, similar work was reported by Pierce *et al.,* (2024) on Heavy Metal(oid)s Contamination and Potential Ecological Risk Assessment in Agricultural Soils

#### *4.3.3 Enrichment factor*

The EF values of samples are presented in Table 7. Fe was used as a normalization element in the calculation. The enrichment factor values of Zn in all the sample sites ranged from 0.026 to 3.22 with all the sites having no enrichment excerpt in Apir Mechanic Workshop with moderate enrichment. This indicates the element is of anthropogenic origin. The enrichment factor values of Ni in all the sample sites ranged from 0.0222 to 6.29, it was observed that, there is no enrichment in North Bank, moderately enrichment in Rice Mill, Industrial Layout, Teaching Hospital and moderately severe enrichment at Apir Mechanic Workshop respectively. In the case of Pb, the enrichment factor values ranged from 54.2 to 4717 in all the sampling sites with the values been in the range of extremely severe enrichment. That of Cu, it ranges from 1.49 to 17.2 in all the sampling sites, the results obtained fall within the severe enrichment excerpt that of North Bank sampling site. It is a fact that, EF less than 2 means the element in the soil is originated predominantly from lithogenous materials while an EF value greater than 2 indicates the element is of anthropogenic origin (Szefer *et al.,* 1996). Therefore, it can be said that the origin of heavy metals in the soil from the study were from anthropogenic origin or lithogenous materials. The result of Cu obtained in the study conform with the work of Salami *et al.,* (2021) but differs with other elements.

#### *4.3.4 Ecological risk index*

The terminologies used to describe potential ecological risk factor by Hakanson (1980) were also adopted in this work. Ei < 40 indicates low potential ecological risk, 40 ≤ Ei < 80 is moderate potential ecological risk, 80≤Ei< 160 means considerable potential ecological risk, 16 ≤ Ei < 320 indicates high potential ecological risk and Ei ≥ 320 is very high ecological risk. In Table 8, all the potential ecological risk index values were less than 40. This clearly showed that the soils of the study sites have low potential ecological risk. The ecological risk index is a comprehensive index used to assess heavy metals in soil. The terminologies used for describing the ecological risk index are as follows _Hakanson (1980): *RI* < 150 indicates low ecological risk, 150 ≤ RI < 300

means moderate ecological risk, 300 ≤ RI < 600 indicates considerable ecological risk and *RI* ≥ 600 means very high ecological risk. All the ecological risk indexes in Table 8 were below 150 which mean the soils in the study sites were of low ecological risk. It was obvious that the soils in the studied sites were of low ecological risk of contamination and low ecological risk to public health. Hence, these soils may not be too sensitive to heavy metals contamination. Similar results were reported by Pierce et al., (2024) and Salami et al., (2021) but differs with that of Broomandi *et al.,* (2020). The result is also in agreement with Cf and Igeo assessments, showing that the sampled environment has a low level of contamination.

### *4.4 Assessment of Human Health Risk*

The health risk assessment was carried out to evaluate the extent to which contact with heavy metal through ingestion, inhalation and dermal contact can affect human health

#### *4.4.1 Chronic Daily Intake*

International regulatory bodies like the US EPA defined the reference oral dose (RfD) for heavy metals as an estimate of the tolerable daily intake of a metal by human population that will pose no health risk during a life time. It is usually employed for the assessment of EPA's non-carcinogenic health risk (Mahmoud and Abdel-Mohsein, 2015). The ingestion, dermal and inhalation reference doses for Fe as set by US EPA were 0.7, 0.8 and 0.14 mg $kg^{-1}$ $day^{-1}$ respectively. The estimated daily intake of Fe obtained in this study for the three pathways (Ingestion, Dermal and Inhalation) ranges from 2.16×10-6 to 3.48 ×10-11 mg $kg^{-1}$ $day^{-1}$ in all the sampling sites and across the age groups. These values are below the reference oral dose for Fe indicating that the human population within these locals may be ingesting safe levels of Fe. This result is consistent with the finding of Uchechi *et al.,* (2018) on Human health risk assessment of heavy metals in soils and commonly consumed food crops from quarry sites located at Isiagwu, Ebonyi State. The daily intake of Zn across the sampling sites by children range from $1.47\times10^{-6}$ to $5.58\times10^{-11}$ mg $kg^{-1}$ $day^{-1}$ while that of adult ranges from $1.56\times10^{-7}$ to $2.39\times10^{-11}$ mg $kg^{-1}$ $day^{-1}$ respectively. These values are below the oral, dermal and inhalation doses of 0.3, 0.3, 0.06 mg kg−1 Zn $Day^{-1}$ respectively as it recommended to be safe. The estimated daily intake of Ni obtained in this study range from $1.48\times10^{-6}$ to $5.63\times10^{-11}$ mg $kg^{-1}$ $day^{-1}$ and $1.56\times10^{-7}$ to $2.41\times10^{-11}$ for children and adult respectively. These values are below the reference doses of ingestion, dermal and inhalation for Ni as set by US EPA were 0.02, 0.0206 and 0.0054 mg $kg^{-1}$ $day^{-1}$ respectively. The daily intake of Pb across the sampling sites by children range from $2.39\times10^{-4}$ to $3.86\times10^{-10}$ and that of adult, $2.56\times10^{-5}$ to $1.66\times10^{-10}$ mg $kg^{-1}$ $day^{-1}$ respectively. These values are below the tolerable daily intake, dermal and inhalation of 0.0035, 0.00353 and 0.000525 mg $kg^{-1}$ $day^{-1}$ respectivel as set by the US EPA. In the same vein, the daily intake of Cu obtained in this study range from $3.02\times10^{-6}$ to $8.45\times10^{-11}$ and $3.23\times10^{-7}$ to $2.71\times10^{-11}$ mg $kg^{-1}$ $day^{-1}$. This suggest a safe oral, dermal and inhalation doses since values are below the recommended daily intake of 0.04, 0.0402 and 0.012 mg $kg^{-1}$ respectively as defined by regulatory bodies. These results indicate, that the human population within these locals may be safe contamination of these metals. These results are consistent with the previous work reported by Uchechi *et al.,* (2018). And the results showed that daily intake of metals were in the following order Pb < Fe < Cu < Ni < Zn for both adults and children. Generally, ingestion constitutes the highest pathway of the daily intake of heavy metals in all the sampling areas followed by dermal contact and inhalation pathways respectively. This indicate that, people working in these areas are highly exposed to these metals through oral, dermal and inhalation pathways. As observed in the results, the children are expected to be more susceptible than adults as playing with sand is predominant among children in the research sites and the ingestion route in children is attributable to the frequency of hand-to-mouth habit.

*4.4.2 Non-Carcinogenic risk*

In order to give an estimate of the non-carcinogenic health risk due to oral exposure to heavy metals, the target hazard quotient and hazardous indexes of heavy metal in soils were calculated and presented in Tables 10 and 11 respectively. The results show that, across all the heavy metals calculated for both children and adult populations, the Hazard Quotient (HQ) and Hazard Index (HI) values remain below one for all three pathways (ingestion, dermal and inhalation). This indicates that, there is no evident risk of chronic health effects to the population. Hence, the population under study is considered to be safe from the heavy metals. From the findings, it can be suggested that the most substantial contributor to non-carcinogenic risk for both children and adults is the ingestion pathway, followed by the dermal pathway. Inhalation is identified as the least influential pathway in terms of risk contribution. This assertion conforms with the work of Okorie *et al.,* (2024) on Physicochemical properties and health risk assessment of selected heavy metals from soil and borehole water in Ifite-Awka, Anambra State, Nigeria. Uchechi et al., (2018) reported the hazard quotient of Mn and Pb was > 1 from a quarry site, the difference may be due to different activities on the locations. The estimated Hazard Index (HI) of all the elements in soil samples of all the study sites were below the acceptable safe level of one (<1) set by USEPA. This indicated that there is no likelihood of non-carcinogenic health risks effects. A similar study by Orosun *et al.* (2020) also reported an estimated Hazard Index of less than one (< 1) in all the soil samples. In contrast to the finding in this study, Liang *et al.* (2017) and Jimoh *et al.* (2020) reported an elevated hazard index estimate above the acceptable safe level and suggested potential health risk to the local residents in each case.

*4.4.3 Carcinogenic risk assessment (CRA)*

The cancer slope factors were used to estimate the carcinogenic risk (CR) and results are presented in Table 12. The predictable life time risk to cancer due to Ni intake estimated in this study in all the entry routes range from $1.08\times10^{-7}$ to $4.39\times10^{-12}$ while that of Pb range from $1.78\times10^{-7}$ to $1.39\times10^{-12}$ across the age group respectively. With regards to US EPA standard, these values fall below the range of predictable lifetime risk to cancer. Average carcinogenic risk values obtained for Ni and Pb in this study, suggest that children may susceptible or prone to cancer after long period because of their behavioral characteristics (e.g., outdoor activities, mouthing non-food objects, and sucking their hands or fingers) and are at greater risk of exposure to contaminants in soils. A study by Orosun *et al.* (2020), for carcinogenic risk assessment in soil samples reports values above the safe region recommended by USEPA.

### *4.5 Statistical Analysis*

The results of statistical analysis of the analyzed heavy metals in all the sampling sites as presented in Appendices 1-5 shows that, there is a statistical difference between the sites as the p-value is <0.05, hence the null hypothesis is rejected.

## 5.0 Conclusion

Soil is a major pool for contaminants and the heavy metals contamination of surface soil and it has become a severe environmental issue and a potential threat to food safety worldwide. The physicochemical parameters analyzed in this work were all within the WHO permissible limit. The present study assessed the heavy metals levels, identifying a possible source as well as an ecological risk assessment (Igeo, EF, Cf and Er) in the soil and were all within the acceptable limit. Human health assessment revealed that ingestion, inhalation and dermal

pathways are routes through which humans are exposed to the heavy metals with ingestion pathway being the major one. Hazard Quotients (HQ) and Hazard Index (HI) in the study were less than 1 which indicates that the hazards are low in all the locations. Thus, it was concluded that the studied environment has no likelihood of non-carcinogenic health risks effects and based on Cancer Risk values of Ni and Pb pose low cancer risk to human beings.

## 6.0 Challenges and Future Research Directions

The limited number of sampling locations within Makurdi metropolis was a major challenge. The selected areas represented important activity zones such as mechanic workshops, industrial layouts, rice mills, and hospital environments, but the samples may not fully represent the entire metropolis. Different locations may have varying levels of contamination due to differences in human activities, traffic density, waste disposal practices, and industrial operations. Another challenge was the limitation in the number of heavy metals analyzed. Only Fe, Zn, Ni, Pb, and Cu were investigated in this study. Other toxic metals such as cadmium (Cd), chromium (Cr), arsenic (As), and mercury (Hg), which are also known to pose serious environmental and health risks, were not included. Their absence may limit the overall understanding of soil contamination in the study area. Seasonal variation also posed a challenge during the study. Soil properties and heavy metal concentrations can change between dry and rainy seasons due to runoff, flooding, erosion, and leaching. Since the samples were collected at a particular period, the study may not fully capture the seasonal changes in heavy metal distribution within the environment. In addition, the study focused mainly on surface soils. Heavy metals can move downward into deeper soil layers and even contaminate groundwater over time. Therefore, analyzing only surface soils may not provide complete information on the long-term movement and accumulation of heavy metals in the environment. Another limitation was the dependence on standard ecological and human health risk assessment models. These models use general exposure assumptions that may not completely reflect the actual lifestyle, feeding habits, occupation, and environmental exposure patterns of people living in Makurdi metropolis. As a result, the estimated risks may differ slightly from real-life exposure conditions. Financial and laboratory constraints also affected the study. Advanced analytical equipment and repeated sampling across many locations require high costs and technical support. These limitations may reduce the number of samples analyzed and the depth of investigation that could be achieved.

Future studies should include more sampling locations across Makurdi metropolis and surrounding communities. Expanding the study area will provide a broader understanding of the distribution and sources of heavy metal contamination in the region. There is also a need for future research to investigate additional heavy metals such as cadmium, arsenic, chromium, and mercury because of their high toxicity and possible health effects. Including more contaminants will give a more complete assessment of soil quality and environmental safety. Further studies should examine seasonal variations in heavy metal concentrations by collecting samples during both dry and rainy seasons. This will help researchers understand how climate and weather conditions influence the movement, accumulation, and bioavailability of heavy metals in soils. Future research should also investigate deeper soil layers and groundwater sources around the study areas. This is important because heavy metals can gradually leach into underground water systems and become a threat to drinking water quality and agricultural activities. Another important direction is the assessment of heavy metal accumulation in food crops grown around the study sites. Since people may consume vegetables and crops cultivated on contaminated soils, there is a need to determine the transfer of heavy metals from soil into plants and the possible health implications for consumers. Biomonitoring studies involving humans and animals living near the contaminated areas should also be encouraged. Such studies can help determine the actual level of exposure to heavy metals through blood, urine, hair, or other biological samples. Future

researchers should equally focus on identifying the exact sources of heavy metal contamination in Makurdi metropolis. This can help environmental agencies and policymakers develop proper control measures for waste disposal, industrial emissions, automobile repairs, and other pollution-related activities. Finally, more studies should explore sustainable remediation methods such as phytoremediation, soil washing, and the use of organic amendments to reduce heavy metal contamination in soils. These approaches may help improve soil quality and reduce future ecological and health risks within the study area.

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The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

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