Heavy Metal Contamination in a Dumpsite Soil: An Evaluation of Health Risks

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ABSTRACT

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| The unscientific disposal of waste is a main source of soil pollution. In order to mitigate heavy metal exposure strategies, the main purpose of the present study was to provide background data to understand the effect of municipal solid waste dumping on topsoil and the health risk assessment of soil heavy metals. Health risk assessment provides information for the reduction of environmental pollution and for reducing its effects. Soil samples were taken at three sampling points (10, 20 and 30 m) away from the dumping waste at depths of 15, 30 and 45cm. Heavy metals, including Cu, Pb, Zn, Ni and Cd, were analysed using standard methods. The level of contamination of heavy metals in a dumpsite soil was assessed by contamination indices, including contamination factor (CF), degree of contamination (CD), pollution load index (PLI) and geo-accumulation index (I-geo). The health risks via the three pathways were detected. The carcinogenic and non-carcinogenic health risks and lifetime cancer risk were evaluated based on inhalation, ingestion, and dermal routes of exposure to metals. CF showed low environmental risk potential as CF values were less than one ($CF<1$). Geo-accumulation index (1-geo) presents uncontaminated to moderately contaminated as I-geo values less than one ($I-geo<1$). The degree of contamination was low with the CD values ranging within Cd$<5$. PLI of this study suggests that there was no heavy metal pollution risk with PLI values less than one (PLI < 1). The order of overall contamination at the three sampling depths for CD was 15 > 30 > 4$5cm$ while that of the PLI was still 15 > 30 > 4$5cm$. No major risk was contributed for adults and children in the dumping site as the risk index (HI), which is the summation of hazard quotients of individual metals, posed no harmful effect to both adults and children's health as HI $<$ 1. Overall, LCR for adults was in the range of 1 × 10-7 – 10-8, whereas LCR for children was in the range 1 × 10– 10-8, which is regarded as negligible for the three pathways via ingestion, inhalation and dermal contact. |

*Keywords: Evaluation, Health Risk Assessment, Heavy Metals Contamination, Dumpsite Soil*

1. INTRODUCTION

“Open dumping of municipal solid wastes is known for environmental concern with respect to the threat they have generated and continue to pose. Leachate is generally produced in conjunction with precipitation that infiltrates through the refuse. Leachate migration contaminates the soil with heavy metals such as Pb, Cu, Zn, Fe, Mn, Cr and Cd, and these heavy metals in solid wastes lead to severe harm because they cannot be biodegraded” (Nta 2021).

Heavy metals are a prevailing tracer for monitoring the impact of municipal solid waste dumping on soils. In a study conducted by Nta *et al*., (2020), “on soil quality as affected by municipal solid waste dumping, results shows that heavy metal concentration (Zn, Cu, Mn, Fe, Pb, Cd, Cr, Cl and Ni) were found to be high near the dumpsite and decreased along the soil depth and distance from the dumping site”.

Nta and Odiong (2017) reported that “one of the main objectives in the design of a landfill site should be proper management of polluted water and leachate migration, therefore mitigating the risk of health and environmental damage. In the same study, it was also reported that suitable sites should be specially selected with attention being given to the soil, to ensure that it does not become overloaded and unable to attenuate or retain the potential pollutants”.

“Heavy metal pollution of soil is an important environmental problem. Soil contamination by heavy metals from waste disposal sites is a significant problem in industrial and urban areas. Heavy metals in soil have strong mobility, high toxicity and are nondegradable, which makes them easily absorbed and enriched by crops in production activities. Therefore, heavy metals seriously affect the yield and quality of crops and accumulate in the human body via the food chain to endanger human health” (Liu et al., 2022).

Notably, “hazardous metals in soil have been shown to impede the degradation of organic pollutants significantly” (Tripathi et al., 2024). In order to mitigate heavy metal exposure strategies, the main purpose of the present study was to provide background data to understand the effect of municipal solid waste dumping on topsoil and the health risk assessment of soil heavy metals. Health risk assessment provides information for the reduction of environmental pollution and for reducing its effects. A health risk assessment model is important for the development of regulations and strategies to reduce chemical exposure for the protection of public health. The objectives were to (1) evaluate the circulation of metals in the dumpsite soil in the study area, (2) evaluate potential indicators, the potential environmental risk index (Er) and the environmental risk index (RI) imposed by the assessment of the risk for heavy metals and the health impact that metals in the soil.

2. material and methods

**2.1 *Study Area***

This study was carried out on the Uyo village road. Uyo village road is situated in the Uyo local government area. Uyo is the capital city of Akwa Ibom State, Nigeria. It’s situated at 5.03° North latitude, 7.93° East longitude and 196 meters elevation above the sea level. The average annual temperature in Uyo is 26.4°C. The average rainfall is 2509 mm.

**2.2 *Sample Collection and Analysis***

Soil samples were taken at three sampling points (10, 20 and 30 m) away from the dumping waste at depths of 15, 30 and 45cm. Heavy metals, including Cu, Pb, Zn, Ni and Cd, were analysed using standard methods.

**2.3 *Heavy Metal Risk Assessment***

The level of contamination of heavy metals in a dumpsite soil was assessed by contamination indices, including contamination factor (CF), degree of contamination (CD), pollution load index (PLI) and geo-accumulation index (I-geo). These indices and their contamination level descriptions are presented in Table 1. The contamination factor (CF) and the geo-accumulation index are indices for assessing the contamination level of individual heavy metals. The degree of contamination (CD) index and the pollution load index (PLI) measure the overall degree of heavy metal contamination of a sampling location. Hence, results of CF and Igeo, as well as CD and PLI, could be used to validate each other, respectively.

Table 1: **Contamination Models and Description of Models**

|  |  |  |  |
| --- | --- | --- | --- |
|  Contamination indices (CI) | Models | Values | Degree of Contamination |
|  Contamination Factor (CF) | $$CF=\frac{C\_{m}}{C\_{b}}$$ | $CF<1$ $1<CF<3$ $3<CF<6$ $CF>6$  | LowModerateConsiderable Very high |
| Degree of contamination (CD) | $$CD=\sum\_{}^{}CF\_{i}$$ | $$CD<5$$$$5<CD<10$$$$10<CD<20$$$$CD>20$$ | LowModerateConsiderableVery high |
| Pollution load index (PLI)  | $$PLI=\left(CF\_{1}×CF\_{2}×CF\_{3}×…….CF\_{n}\right)^{1/n}$$ | $$PLI<1$$$$PLI=1$$$$PLI>1$$ | PerfectionBase line level of pollution Deterioration of site quality |
| Geo-accumulation index (Igeo) | $$Igeo=log\_{2}\left(^{C\_{m}}/\_{1.5C\_{b}}\right)$$ | $$Igeo<0$$$$0<Igeo<1$$$$1<Igeo<2$$$$2<Igeo<3$$$$3<Igeo<4$$$$4<Igeo<5$$$$Igeo>5$$ | Uncontaminated Uncontaminated to moderately contaminated Moderately contaminatedModerately to strongly contaminatedStrongly contaminatedStrongly to extremely contaminatedExtremely contaminated |

Where Cm is the measured concentration of the heavy metal,$ C\_{s}$ is the background concentration (Håkanson, 1980; Thomlinson *et al.,* 1980; Muller, 1969).

***2.4 Heavy Metal Risk Assessment***

***2.4.1. Potential Ecological Risk Index***

The toxicity and ecological hazards posed by heavy metals, as suggested by Zhu *et al*. (2012) and first reported by Hakanson (1980), were used to determine the potential risk of individual heavy metals on dumpsite soil, Equation (1) as follows:

 Eri = Cri × Tr i = (Cis/Cin) × Tir  (1)

Where; Tir is the toxic-response factor for a single heavy metal contamination and was taken as 1 for Zn, 5 for Cu and Pb, 13.3 for Ni, and 30 for Cd as suggested by (Guo *et al*., 2012; Islam *et al*., 2015). Cir is an index for contamination of a given heavy metal, Cis is the present concentration of heavy metal in the dump site soil, and Cin is the reference value of heavy metal in the soil. The reference values of the average shale in the urban environment used in this work are from Fadigas *et al*. (2014). These values are: 35.1 mg kg−1 for Cu, 0.5 mg kg−1 for Cd, 17 mg kg−1 for Pb, 59.9 mg kg−1 for Zn and 13.2 mg kg−1 for Ni. The sum of potential individual risks (Eir) is the potential ecological risk index (RI) and was calculated using Equation (2), which is defined as:

 RI = ∑ Eri = ∑ Tr i (Cis/Cin) (2)

The potential ecological hazard and the risk criteria resulting in heavy metal accumulation in the dumpsite soils are classified into risk categories and given in Table 2.

**Table 2. Classification of Potential Ecological Risk Index (Eir) and Risk index (RI)**

|  |  |  |  |
| --- | --- | --- | --- |
| EiR  | Risk classification | RI | Risk classification  |
| EiR < 40  | Low risk | RI < 50 | Low risk |
| 40 ≤ EiR < 80 | Moderate risk | 50 ≤ RI < 200 | Moderate risk |
| 80 ≤ EiR < 160 | Considerable risk | 200 ≤ RI < 300 | Considerable risk |
| 160 ≤ EiR < 320 | High risk | RI ≥ 300 | High risk |
| EiR ≥ 320 | Very high risk |  |  |

Note: Adapted from Trujillo-González *et al*. 2016 based on ecological risk classification introduced by Hakanson (1980).

**2.4.2 Health Risk Assessment**

Three key pathways through which humans are exposed to contaminants, according to (USEPA 1989; USEPA 1996; Zheng *et al*., 2010) are: (1) ingestion (Ding); (2) inhalation (Dinh); and (3) dermal contact (Lee *et al*., 2006; Luo *et al*., 2012). The health risks via the three pathways were detected using Equations (3–5):

$ D\_{ing}=\left[\frac{C×R\_{ing}×ED×EF}{\left(AT×BW\right)×10^{-6}}\right]$ (3)

$ D\_{inh}=\left[\frac{C×R\_{inh}×ED×EF}{AT×BW×PEF}\right]$ (4)

$ D\_{dermal}=\left[\frac{C×AF×SA×ED×EF×ABS}{\left(AT×BW\right)×10^{-6}}\right]$ (5)

where C is the concentration of heavy metal on dumpsite soil (mg/kg), RIng is the ingestion rate (mg/day), ED is the exposure duration (years), EF is the exposure frequency (days/year), AT is the averaging time, BW is the average body weight (kg), (days), RInh is the inhalation rate (mg/cm2), PEF is the particle emission factor (m3/kg), AF is the skin adherence factor for soil (mg/cm2-day), SA is the surface area of the exposed skin that is in contact with the sample (cm2), and ABS is the dermal absorption factor (unit-less). Exposure factors used in the non-carcinogenic Risk Ddermal estimate are given in Table 3.

**Table 3.** Exposure Variables used in Non-Carcinogenic Exposure Ddermal Assessment [**USEPA 2002**]

|  |  |
| --- | --- |
| IngR  | 100 mg/day (adult), 200 mg/day (children) |
| EF | 180 days |
| ED | 24 years (adult), 6 years (children) |
| BW | 70 kg (adult), 15 kg (children) |
| AT  | 365 × ED adult/children |
| InhR | 20 mg/cm2 |
| PEF | 1.36 × 109 m3/kg |
| SA  | 2145 cm2 event−1 (adult), 1150 cm2 event−1 (child) |
| AFsoil  | 0.07 mg cm−2 day−12 (adult), 0.2 mg cm−2 day−1 (child) |
| ABS | 0.001 |

**2.4.3. Non-Carcinogenic Risk Assessment**

The concentrations of heavy metals on dumpsite soils were applied to assess the adult and children’s health risks, both carcinogenic and non-carcinogenic. Hazard quotient (HQ) calculated to determine non-carcinogenic health risk for each individual heavy metal element is as described in Equation (6) (USEPA 1989).

$ HQ=\frac{D}{RFD}$ (6)

Where RFD reflects the chronic reference dose for each heavy metal (mg/kg-day) as given in Table 4 (USEPA 2012).

**Table 4: Reference Dose RFD (mg/kg-day) for each Heavy Metal**

|  |  |
| --- | --- |
| Heavy metal | RfD (mg/kg/day) |
| Cu | 0.0371 |
| Pb | 0.0035 |
| Zn | 0.3 |
| Ni | 0.91 |
| Cd | 0.001 |

3. results and discussion

***3.1 Heavy Metals Contamination Assessment***

Contamination factors (Cf), the degree of contamination (Cd), the pollution load index (PLI) and geo-accumulation index (I-geo) were calculated to evaluate the level of contamination in a dumpsite soil. Tables 5 and 6 present the CF and Igeo indices of the individual heavy metals detected at different lateral distances and depths in the dumpsite soil. Matching between the CF values of Table 5 and the description of soil contamination in Table 1; Cd, Cu, Pb, Zn and Ni measured at 10, 20 and 30 m lateral distance and at 15, 30 and 45 cm sampling depth revealed low environmental risk potential as CF values were less than one ($CF<1$).

The results of geo-accumulation index (1-geo) as presented in Table 6 show that all the heavy metals under consideration are present in uncontaminated to moderately contaminated, as I-geo values are less than one ($I-geo<1$). This indicates that these heavy metals did not pose any threat of contamination (Table 1) at 10, 20 and 30 m lateral distance and at 15, 30 and 45 cm sampling depth.

**Table 5: Contamination Factors (CF) for Heavy Metals Measured in a Dumpsite Soil**

|  |  |  |  |
| --- | --- | --- | --- |
| HM  | BSLI @ 10m | BSL2 @ 20m | BSL3 @ 30 m |
|  | BSL1A | BSL1B | BSL1C | BSL2A | BSL2B | BSL2C | BSL3A | BSL3B | BSL3C |
| Cd | 0.162 | 0.100 | 0.062 | 0.087 | 0.075 | 0.050 | 0.062 | 0.037 | 0.025 |
| Cu | 0.040 | 0.011 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 |
| Pb | 0.120 | 0.045 | 0.025 | 0.103 | 0.090 | 0.040 | 0.080 | 0.071 | 0.036 |
| Ni | 0.370 | 0.247 | 0.140 | 0.247 | 0.106 | 0.044 | 0.153 | 0.130 | 0.081 |
| Zn | 0.108 | 0.101 | 0.081 | 0.091 | 0.090 | 0.081 | 0.087 | 0.038 | 0.034 |

BSL1, 2, 3 – Borehole Sampling Location No: 1, 2, 3 at 10, 20, 30 m lateral spacing and Suffix A, B, C- 15, 30 and 45 cm in each borehole sampling location.

**Table 6: Geo-accumulation Index (I-geo) of Heavy Metals in a Dumpsite Soil**

|  |  |  |  |
| --- | --- | --- | --- |
| HM  | BSLI @ 10m | BSL2 @ 20m | BSL3 @ 30 m |
|  | BSL1A | BSL1B | BSL1C | BSL2A | BSL2B | BSL2C | BSL3A | BSL3B | BSL3C |
| Cd | 0.108 | 0.066 | 0.014 | 0.058 | 0.050 | 0.033 | 0.041 | 0.025 | 0.016 |
| Cu | 0.026 | 0.007 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.003 |
| Pb | 0.080 | 0.029 | 0.016 | 0.069 | 0.060 | 0.027 | 0.053 | 0.047 | 0.024 |
| Ni | 0.247 | 0.165 | 0.093 | 0.165 | 0.071 | 0.029 | 0.102 | 0.087 | 0.054 |
| Zn | 0.072 | 0.067 | 0.054 | 0.060 | 0.060 | 0.054 | 0.058 | 0.025 | 0.023 |

BSL1, 2, 3 – Borehole Sampling Location No: 1, 2, 3 at 10, 20, 30 m lateral spacing and Suffix A, B, C- 15, 30 and 45cm in each borehole sampling location.

Table 7 showsthe values for the degree of contamination (CD) index and the pollution load index (PLI). Both indices are measures of the degree of overall heavy metal contamination at different sampling distances and depths. Mapping Table 7 with Table 1, the degrees of contamination at 10, 20 and 30 m sampling distances, and at 15, 30 and 45 sampling depths were low with the CD values ranging within Cd$<5$.

The PLI is a measure of the degree of overall heavy metal contamination at 10, 20 and 30 m sampling distances and at 15, 30 and 45 depths. It is therefore expected that both indices could be used to validate one another. Contrary to the expected validation, the PLI of this study suggests that there was no heavy metal pollution risk with PLI values less than one (PLI < 1) at 10, 20 and 30 m sampling distances, 15, 30 and 45 cm (Table 7). The order of overall contamination at the two sampling depths for CD was 15 > 30 > 4$5cm$ while that of the PLI was still 15 > 30 > 4$5cm$.

**Table 7: Degree of Contamination and Pollution Load Index**

|  |  |  |  |
| --- | --- | --- | --- |
| HM  | BSLI @ 10m | BSL2 @ 20m | BSL3 @ 30 m |
|  | BSL1A | BSL1B | BSL1C | BSL2A | BSL2B | BSL2C | BSL3A | BSL3B | BSL3C |
| Cd | 0.800 | 0.504 | 0.314 | 0.534 | 0.367 | 0.221 | 0388 | 0.281 | 0.181 |
| PLI | 0.125 | 0.065 | 0.040 | 0.065 | 0.050 | 0.033 | 0.052 | 0.036 | 0.026 |

***3.2 Health Risk Assessment***

Table 8, 9 and 10 presents the calculated average daily dose (ADD) via ingestion (mg/kg-day), exposure concentration via inhalation (mg/kg-day) and dermal absorption via dermal contact (mg/kg-day) of heavy metals in the dumpsite soil. Table 11, 12 and 13 presents’ hazard quotient (HQ) calculated to estimate non-carcinogenic health risk for each individual heavy metals. The ingestion of dumpsite soil was proven as the main route for non-carcinogenic risk through exposure to heavy metal in adults and children, seconded by dermal contact and thirdly by inhalation exposure at 10, 20 and 30 m lateral distance and at 15, 30 and 45 cm sampling depth. Table 14 present risk index (HI) calculated to determine the risk of carcinogenic health effects pose by heavy metal in a dumpsite soil. According to Table 14 heavy metals posed no harmful effect to both adult and children health as HI $<$ 1. In a similar study by (Nta, 2021), “the estimated health risk values for adults and children were generally lower than the reference dose”. The normal risk index (HI) values for these metals for an individual heavy metals decrease in the following order: Pb>Cd>Cu>Zn>Ni as presented on Table 14 at 10, 20 and 30 m lateral distance and at 15, 30 and 45 cm sampling depth. Table 15, 16 and 17 presents the calculated life cancer risk (LCR) for each individual heavy metals and pathways. While Table 18 present the overall life cancer risk for the three pathways. In general, LCR for adult was in the range of 1 × 10-7 – 10-8 whereas LCR for children was in the range of 1 × 106 – 10-8 at 10, 20 and 30 m lateral distance and at 15, 30 and 45 cm sampling depth for the three pathway resulted from Pb and Cd. Although, LCR below 1 × 10-6 is regarded as negligible for the three pathways via ingestion, halation and dermal contact for adult and children. However, it is important to pay attention to possible health risks due to exposure in the dumpsite soil at closer distance and depth from the dumping waste, as Nta *et al*., (2020), “on soil quality as affected by municipal solid waste dumping, reported that heavy metal concentration (Zn, Cu, Mn, Fe, Pb, Cd, Cr, Cl and Ni) were found to be high near the dumpsite and decreased along the soil depth and distance from the dumping site”.

**Table 8 Average Daily Dose (ADD) via Ingestion (mg.kg-1day-1)**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (Ding) | 20 m (Ding) | 30 m (Ding) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 9.1E-8 | 5.6E-8 | 3.5E-8 | 4.9E-8 | 4.2E-8 | 2.8E-8 | 3.5E-8 | 2.1E-8 | 1.4E-8 |
| Cu | 1.0E-6 | 2.8E-7 | 1.6E-7 | 1.7E-7 | 1.6E-7 | 1.6E-7 | 1.6E-7 | 1.4E-7 | 1.3E-7 |
| Pb | 7.2E-6 | 2.6E-6 | 1.5E-6 | 6.2E-6 | 5.4E-6 | 2.4E-6 | 4.8E-6 | 4.2E-6 | 2.1E-6 |
| Ni | 9.1E-6 | 6.1E-6 | 3.4E-6 | 6.1E-6 | 2.6E-6 | 1.0E-6 | 3.7E-6 | 3.2E-6 | 2.0E-6 |
| Zn | 3.8E-6 | 3.5E-6 | 2.8E-6 | 3.2E-6 | 3.1E-6 | 2.8E-6 | 3.0E-6 | 1.3E-6 | 1.2E-6 |
|  | **Children** |
| Cd | 4.2E-7 | 2.6E-7 | 1.6E-7 | 2.3E-7 | 1.9E-7 | 1.3E-7 | 1.6E-7 | 9.8E-8 | 6.5E-8 |
| Cu | 4.7E-6 | 1.3E-6 | 7.5E-7 | 8.2E-7 | 7.8E-7 | 7.5E-7 | 7.5E-7 | 6.5E-7 | 6.2E-7 |
| Pb | 3.3E-5 | 1.2E-5 | 7.0E-6 | 2.8E-5 | 2.5E-5 | 1.1E-5 | 2.2E-5 | 1.9E-5 | 1.0E-5 |
| Ni | 4.2E-5 | 2.8E-5 | 1.6E-5 | 2.8E-5 | 1.2E-5 | 5.0E-6 | 1.7E-6 | 1.5E-5 | 9.3E-6 |
| Zn | 1.7E-5 | 1.6E-5 | 1.3E-5 | 1.5E-5 | 1.4E-5 | 1.3E-5 | 1.4E-5 | 6.2E-6 | 5.6E-6 |

**Table 9 Exposure Concentration (EC) via Inhalation (mg.kg-1day-1)**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (Dinh) | 20 m (Dinh) | 30 m (Dinh) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 6.7E-11 | 4.1E-11 | 2.5E-11 | 3.6E-11 | 3.1E-11 | 2.0E-11 | 2.5E-11 | 1.5E-11 | 1.0E-11 |
| Cu | 7.5E-10 | 2.1E-10 | 1.1E-10 | 1.2E-10 | 1.2E-10 | 1.1E-10 | 1.1E-10 | 1.0E-10 | 9.8E-11 |
| Pb | 5.3E-9 | 1.9E-9 | 1.1E-9 | 4.5E-9 | 3.9E-9 | 1.7E-10 | 5.5E-9 | 3.1E-9 | 1.5E-9 |
| Ni | 6.7E-9 | 4.4E-9 | 2.5E-9 | 4.4E-9 | 1.9E-9 | 8.0E-10 | 2.7E-9 | 2.3E-9 | 1.4E-9 |
| Zn | 2.8E-9 | 2.6E-9 | 2.9E-9 | 2.3E-9 | 2.3E-9 | 2.0E-9 | 2.2E-9 | 9.8E-10 | 8.9E-10 |
|  | Children |
| Cd | 3.1E-10 | 1.9E-10 | 1.2E-10 | 1.6E-10 | 1.4E-10 | 9.6E-11 | 1.2E-10 | 7.2E-11 | 4.8E-11 |
| Cu | 3.5E-9 | 9.9E-10 | 5.5E-10 | 6.0E-10 | 5.8E-10 | 5.5E-10 | 5.5E-10 | 4.8E-10 | 4.5E-10 |
| Pb | 2.4E-8 | 9.2E-9 | 5.1E-9 | 2.1E-8 | 1.8E-8 | 8.3E-9 | 1.6E-8 | 1.8E-8 | 7.4E-9 |
| Ni | 3.1E-8 | 2.0E-8 | 1.1E-8 | 2.0E-8 | 9.0E-9 | 3.7E-9 | 1.2E-8 | 1.1E-8 | 6.8E-9 |
| Zn | 1.3E-8 | 1.2E-8 | 9.7E-9 | 1.1E-8 | 1.0E-8 | 9.7E-9 | 1.0E-8 | 4.5E-9 | 4.1E-9 |

**Table 10 Dermal Absorption Dose (DAD) (mg.kg-1day-1)**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (Dder) | 20 m (Dder) | 30 m (Dder) |
| **Adult** |
| 15 cm | 30 cm | 45 cm | 15 cm | 30 cm | 45 cm | 15 cm | 30 cm | 45 cm |
| Cd | 1.3E-10 | 8.4E-11 | 5.2E-11 | 7.4E-11 | 6.3E-11 | 4.2E-11 | 5.2E-11 | 3.1E-11 | 2.1E-11 |
| Cu | 1.5E-9 | 4.3E-10 | 2.4E-10 | 2.6E-10 | 2.5E-10 | 2.4E-10 | 2.4E-10 | 2.1E-10 | 2.0E-10 |
| Pb | 1.0E-8 | 4.0E-9 | 2.2E-9 | 9.3E-9 | 8.1E-9 | 3.6E-9 | 7.2E-9 | 6.4E-9 | 3.2E-9 |
| Ni | 1.3E-8 | 9.1E-9 | 5.2E-9 | 9.1E-9 | 3.9E-9 | 1.6E-9 | 5.6E-9 | 4.8E-9 | 3.0E-9 |
| Zn | 5.7E-9 | 5.3E-9 | 4.2E-9 | 4.8E-9 | 4.7E-9 | 4.2E-9 | 4.6E-9 | 2.0E-9 | 1.8E-9 |
|  | **Children** |
| Cd | 9.8E-10 | 6.0E-10 | 3.7E-10 | 5.2E-10 | 4.5E-10 | 3.0E-10 | 3.7E-10 | 2.2E-10 | 1.5E-10 |
| Cu | 1.0E-8 | 3.1E-9 | 1.7E-9 | 1.8E-9 | 1.8E-9 | 1.7E-9 | 1.7E-9 | 1.5E-9 | 1.4E-9 |
| Pb | 7.7E-8 | 2.8E-8 | 1.6E-8 | 6.6E-8 | 5.7E-8 | 2.6E-8 | 5.1E-8 | 4.5E-9 | 2.3E-8 |
| Ni | 9.8E-8 | 6.5E-8 | 3.7E-8 | 6.5E-8 | 2.8E-8 | 1.1E-8 | 4.0E-8 | 3.4E-8 | 2.14E-8 |
| Zn | 4.1E-8 | 3.8E-8 | 3.0E-8 | 3.4E-8 | 3.4E-8 | 3.0E-8 | 3.3E-8 | 1.4E-8 | 1.3E-8 |

**Table 11 Non-Carcinogenic Risks Assessment of Heavy Metals via Ingestion**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (HQing) | 20 m (HQing) | 30 m (HQing) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 9.1E-5 | 5.6E-5 | 3.5E-5 | 4.9E-5 | 4.2E-5 | 2.8E-5 | 3.5E-5 | 2.1E-5 | 1.4E-5 |
| Cu | 2.6E-5 | 7.5E-6 | 4.3E-6 | 4.5E-6 | 4.3E-6 | 4.3E-6 | 4.3E-6 | 3.7E-6 | 3.5E-6 |
| Pb | 2.0E-3 | 7.4E-4 | 4.2E-4 | 1.7E-3 | 1.5E-3 | 6.8E-4 | 1.3E-3 | 1.2E-3 | 6.0E-4 |
| Ni | 1.0E-5 | 6.7E-6 | 3.7E-6 | 6.7E-6 | 2.8E-6 | 1.0E-6 | 4.0E-6 | 3.5E-6 | 2.1E-6 |
| Zn | 1.2E-5 | 1.1E-5 | 9.3E-6 | 1.0E-5 | 1.0E-5 | 9.3E-6 | 1.0E-5 | 4.3E-6 | 4.0E-6 |
|  |  |  |  |  |  |  |  |  |  |
|  | **Children** |
| Cd | 4.2E-4 | 2.6E-4 | 1.6E-4 | 2.3E-4 | 1.9E-4 | 1.3E-4 | 1.6E-4 | 9.8E-5 | 6.5E-5 |
| Cu | 1.2E-4 | 3.5E-5 | 2.0E-5 | 2.2E-5 | 2.1E-5 | 2.0E-5 | 2.0E-5 | 1.7E-5 | 1.6E-5 |
| Pb | 9.4E-3 | 3.4E-3 | 2.0E-3 | 8.0E-3 | 7.1E-3 | 3.1E-3 | 6.2E-3 | 5.4E-3 | 2.8E-3 |
| Ni | 4.6E-5 | 2.7E-5 | 1.7E-5 | 3.0E-5 | 1.3E-5 | 5.4E-6 | 1.8E-6 | 1.6E-5 | 1.0E-5 |
| Zn | 5.6E-5 | 5.3E-5 | 4.3E-5 | 5.0E-5 | 4.6E-5 | 4.3E-5 | 4.6E-5 | 2.0E-5 | 1.8E-5 |

**Table 12 Non-Carcinogenic Risks Assessment of Heavy Metals via Inhalation**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (HQinh) | 20 m (HQinh) | 30 m (HQinh) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 6.7E-8 | 4.1E-8 | 2.5E-8 | 3.6E-8 | 3-1E-8 | 2.0E-8 | 2.5E-8 | 1.5E-8 | 1.0E-8 |
| Cu | 2.0E-8 | 5.6E-9 | 2.9E-9 | 3.2E-9 | 3.2E-9 | 2,9E-9 | 2.9E-9 | 2.6E-9 | 2.6E-9 |
| Pb | 1.5E-6 | 5.4E-7 | 3.1E-7 | 1.2E-6 | 1.1E-6 | 4.8E-8 | 1.5E-6 | 8.8E-7 | 4.2E-7 |
| Ni | 7.3E-9 | 4.8E-9 | 2.7E-9 | 4.8E-9 | 2.0E-9 | 8.7E-10 | 2.9E-9 | 2.5E-9 | 1.5E-9 |
| Zn | 9.3E-9 | 8.6E-9 | 9.0E-9 | 7.6E-9 | 7.6E-9 | 6.6E-9 | 7.3E-9 | 3.2E-9 | 2.9E-9 |
|  | **Children** |
| Cd | 3.1E-7 | 1.9E-7 | 1.2E-7 | 1.6E-7 | 1.4E-7 | 9.6E-8 | 1.2E-7 | 7.2E-8 | 4.8E-8 |
| Cu | 9.4E-8 | 2.6E-8 | 1.4E-8 | 1.6E-8 | 1.5E-8 | 1.4E-8 | 1.4E-8 | 1.2E-8 | 1.2E-8 |
| Pb | 6.8E-6 | 2.6E-6 | 1.4E-6 | 6.0E-6 | 5.1E-6 | 2.3E-6 | 4.5E-6 | 4.0E-6 | 2.1E-6 |
| Ni | 1.4E-8 | 2.1E-8 | 1.2E-8 | 2.1E-8 | 9.8E-9 | 4.0E-9 | 1.3E-8 | 1.2E-8 | 7.4E-9 |
| Zn | 4.3E-8 | 4.0E-8 | 3.2E-8 | 3.6E-8 | 3.3E-8 | 3.2E-8 | 3.3E-8 | 1.5E-8 | 1.3E-8 |

**Table 13 Non-Carcinogenic Risks Assessment of Heavy Metals via Dermal Contact**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (HQder) | 20 m (HQder) | 30 m (HQder) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 1.3E-7 | 8.4E-8 | 5.2E-8 | 7.4E-8 | 6.3E-8 | 4.2E-8 | 5.2E-8 | 3.1E-8 | 2.1E-8 |
| Cu | 4.0E-8 | 1.1E-8 | 6.4E-9 | 7.0E-9 | 6.7E-9 | 6.4E-9 | 6.4E-9 | 5.6E-9 | 5.3E-9 |
| Pb | 2.8E-6 | 1.1E-6 | 6.2E-7 | 2.6E-6 | 2.3E-6 | 1.0E-6 | 2.0E-6 | 1.8E-6 | 9.1E-7 |
| Ni | 1.4E-8 | 1.0E-8 | 5.7E-9 | 1.0E-8 | 4.2E-9 | 1.7E-9 | 6.1E-9 | 5.2E-9 | 3.2E-9 |
| Zn | 1.9E-8 | 1.7E-8 | 1.4E-8 | 1.6E-8 | 1.5E-8 | 1.4E-8 | 1.5E-8 | 6.6E-9 | 6.0E-9 |
|  | **Children** |
| Cd | 9.8E-7 | 6.0E-7 | 3.7E-7 | 5.2E-7 | 4.5E-7 | 3.0E-7 | 3.7E-7 | 2.2E-7 | 1.5E-7 |
| Cu | 2.6E-7 | 8.3E-8 | 4.5E-8 | 4.8E-8 | 4.8E-8 | 4.5E-8 | 4.5E-8 | 4.0E-8 | 3.7E-8 |
| Pb | 2.2E-5 | 8.0E-6 | 4.5E-6 | 1.8E-5 | 7.4E-6 | 7.4E-6 | 1.4E-5 | 1.2E-5 | 6.5E-6 |
| Ni | 1.0E-7 | 7.1E-8 | 4.0E-8 | 7.1E-8 | 3.0E-8 | 1.2E-8 | 4.3E-8 | 3.7E-8 | 2.3E-8 |
| Zn | 1.3E-7 | 1.2E-7 | 1.0E-7 | 1.1E-7 | 1.1E-7 | 1.0E-7 | 1.1E-7 | 4.6E-8 | 4.3E-8 |

**Table 14 Risk Index (HI)**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (HI) | 20 m (HI) | 30 m (HI) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 9.1E-5 | 5.6E-5 | 3.5E-5 | 4.9E-5 | 4.2E-5 | 2.8E-5 | 3.5E-5 | 2.1E-8 | 1.4E-5 |
| Cu | 2.6E-5 | 7.5E-6 | 4.3E-6 | 4.5E-6 | 4.3E-6 | 4.3E-6 | 4.3E-6 | 3.7E-6 | 3.5E-6 |
| Pb | 2.0E-3 | 7.4E-4 | 4.2E-4 | 1.7E-3 | 1.5E-3 | 6.8E-4 | 1.3E-3 | 1.2E-3 | 6.0E-4 |
| Ni | 1.0E-5 | 6.7E-6 | 3.7E-6 | 6.7E-6 | 2.8E-6 | 1.0E-6 | 4.0E-6 | 3.5E-6 | 2.1E-6 |
| Zn | 1.2E-5 | 1.1E-5 | 9.3E-6 | 1.0E-5 | 1.0E-5 | 9.3E-6 | 1.0E-5 | 4.3E-6 | 4.0E-6 |
|  | **Children** |
| Cd | 4.2E-4 | 2.6E-4 | 1.6E-4 | 2.3E-4 | 1.9E-4 | 1.3E-4 | 1.6E-4 | 9.8E-5 | 6.5E-5 |
| Cu | 1.2E-4 | 3.5E-5 | 2.0E-5 | 2.2E-5 | 2.1E-5 | 2.0E-5 | 2.0E-5 | 1.7E-5 | 1.6E-5 |
| Pb | 9.4E-3 | 3.4E-3 | 2.0E-3 | 8.0E-3 | 7.1E-3 | 3.1E-3 | 6.2E-3 | 5.4E-3 | 2.8E-3 |
| Ni | 4.6E-5 | 2.7E-5 | 1.7E-5 | 3.0E-5 | 1.3E-5 | 5.4E-6 | 1.8E-6 | 1.6E-5 | 1.0E-5 |
| Zn | 5.6E-5 | 5.3E-5 | 4.3E-5 | 5.0E-5 | 4.6E-5 | 4.3E-5 | 4.6E-5 | 2.0E-5 | 1.8E-5 |

**Table 15 Carcinogenic Risks Assessment of Heavy Metals via Ingestion**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (LCRing) | 20 m (LCRing) | 30 m (LCRing) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 5.7E-7 | 3.5E-7 | 2.2E-7 | 3.0E-7 | 2.6E-7 | 1.7E-7 | 2.2E-7 | 1.3E-7 | 8.8E-8 |
| Pb | 6.1E-8 | 2.2E-8 | 1.2E-8 | 5.2E-8 | 4.5E-8 | 2.0E-8 | 4.0E-8 | 3.5E-8 | 1.7E-8 |
|  | **Children** |
| Cd | 2.6E-6 | 1.6E-6 | 1.0E-6 | 1.4E-6 | 1.1E-6 | 8.1E-7 | 1.0E-6 | 6.1E-7 | 4.0E-7 |
| Pb | 2.8E-7 | 1.0E-7 | 5.9E-8 | 2.3E-7 | 2.1E-7 | 9.3E-8 | 1.8E-7 | 1.6E-7 | 8.5E-8 |

**Table.16 Carcinogenic Risks Assessment of Heavy Metals via Inhalation**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (LCRinh) | 20 m (LCRinh) | 30 m (LCRinh) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 4.2E-10 | 2.5E-10 | 1.5E-10 | 2.2E-10 | 1.9E-10 | 1.2E-10 | 1.5E-10 | 9.E-11 | 6.3E-11 |
| Pb | 4.5E-11 | 1.6E-11 | 9.3E-12 | 3.8E-11 | 3.3E-11 | 1.4E-12 | 4.6E-11 | 8.6E-11 | 1.2E-11 |
|  | **Children** |
| Cd | 1.9E-9 | 1.1E-9 | 7.5E-10 | 1.0E-9 | 8.8E-10 | 6.0E-10 | 7.5E-10 | 4.5E-10 | 3.0E-10 |
| Pb | 2.0E-10 | 7.8E-11 | 4.3E-11 | 1.7E-10 | 1.5E-10 | 7.0E-11 | 1.3E-10 | 1.1E-10 | 6.2E-11 |

**Table 17 Carcinogenic Risks Assessment of Heavy Metals via Dermal Contact**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (LCRDer) | 20 m (LCRDer) | 30 m (LCRDer) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 8.1E-10 | 5.2E-10 | 3.2E-10 | 4.6E-10 | 3.9E-10 | 2.6E-10 | 3.2E-10 | 1.9E-10 | 1.3E-10 |
| Pb | 6.3E-8 | 2.5E-8 | 1.3E-8 | 5.8E-8 | 5.1E-8 | 2.2E-8 | 4.5E-8 | 4.0E-8 | 2.0E-8 |
|  | **Children** |
| Cd | 6.1E-9 | 3.7E-9 | 2.3E-9 | 3.2E-9 | 2.8E-9 | 1.8E-9 | 2.3E-9 | 1.3E-9 | 9.4E-10 |
| Pb | 6.5E-10 | 2.3E-10 | 1.3E-10 | 5.6E-10 | 4.8E-10 | 2.2E-10 | 4.3E-10 | 3.8E-10 | 1.9E-10 |

**Table 18 Cumulative Life Carcinogenic Risk (∑LCR)**

|  |  |  |  |
| --- | --- | --- | --- |
| HMs | 10 m (LCR) | 20 m (LCR) | 30 m (LCR) |
| **Adult** |
| 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth | 15 cm Depth | 30 cm Depth | 45 cm Depth |
| Cd | 5.7E-7 | 3.5E-7 | 2.2E-7 | 3.0E-7 | 2.6E-7 | 1.7E-7 | 2.2E-7 | 1.3E-7 | 8.8E-8 |
| Pb | 4.7E-8 | 2.5E-8 | 1.1E-7 | 9.6E-8 | 4.2E-8 | 8.5E-8 | 7.5E-8 | 7.5E-8 | 3.7E-8 |
|  | **Children** |
| Cd | 2.6E-6 | 1.6E-6 | 1.0E-6 | 1.4E-6 | 1.1E-6 | 8.1E-7 | 1.0E-6 | 6.1E-7 | 4.0E-7 |
| Pb | 2.8E-7 | 1.0E-7 | 5.9E-8 | 2.3E-7 | 2.1E-7 | 9.3E-8 | 1.8E-7 | 1.6E-7 | 8.5E-8 |

4. Conclusion

The level of contamination of heavy metals in dumpsite soils was assessed by contamination indices. Contamination factors (CF) values for Cd, Cu, Pb, Zn and Ni measured at 10, 20 and 30 m lateral distance and at 15, 30 and 45 cm sampling depth revealed low environmental risk potential as CF values were less than one ($CF<1$). The results of geo-accumulation index (1-geo) revealed that all the heavy metals under consideration are present uncontaminated to moderately contaminated, as I-geo values are less than one ($I-geo<1$). Degree of contamination at 10, 20 and 30 m sampling distances, and at 15, 30 and 45 sampling depths was low, with the CD values ranging within Cd$<5$. PLI of this study suggests that there was no heavy metal pollution risk with PLI values less than one (PLI < 1) at 10, 20 and 30 m sampling distances, 15, 30 and 45 cm. The order of overall contamination at the three sampling depths for CD was 15 > 30 > 4$5cm$ while that of the PLI was still 15 > 30 > 4$5cm$. No major risk was contributed for adults and children in the dumping site as the risk index (HI), which is the summation of hazard quotients of individual metals, posed no harmful effect to both adults' and children's health, as HI $<$ 1. Overall, LCR for adults was in the range of 1 × 10-7 – 10-8 whereas LCR for children was in the range 1 × 106 – 10-8 which is regarded as negligible for the three pathways via ingestion, inhalation and dermal contact.

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References

Nta, S. A. (2021), Health Risk Assessment of Heavy Metals in the Contaminated and Uncontaminated Soils, World Academy of Science, Engineering and Technology International Journal of Agricultural and Biosystems Engineering 15(1): pp. 1-5.

Nta, S. A., Ayotamuno, M. J., Igoni, A. H. and Okparanma, R. H. (2020). Soil Quality as Affected by Municipal Solid Waste Dumping, Asian Soil Research Journal 3(2): pp. 1-11,

NTA, S. A. and ODIONG, I. C. (2017). Impact of Municipal Solid Waste Landfill Leachate on Soil Properties in the Dumpsite*, International Journal of Scientific Engineering and Science,* 1(3): pp. 5-7.

Hakanson, L. (1980).Ecological Risk Index for Aquatic Pollution Control, a Sedimentological Approach*. Water Research. 14, 975– 1001.*

Tomlinson, D. L., Wilson, J. G., Harris, C. R., Jeffrey, D. W. (1980). Problems in the Assessment of Heavy Metals in Estuaries and the Formation of Pollution Index. *Helgolander Meeresunters*. 33, 566-575.

Muller, G. (1969). Index of Geo-accumulation in Sediments of the Rhine river. *Geo journal*. 2(3), 108–118.

Zhu H, Yuan X-Z, Zeng G-M, *et al*. (2012). Ecological risk assessment of heavy metals in sediments of Xiawan Port based on modified potential ecological risk index. Trans Nonferrous Met Soc China. 22: 1470–1477. doi:10.1016/S1003-6326(11)61343-5.

Guo, G., Wu, F., Xie, F, *et al*. (2012) .Spatial distribution and pollution assessment of heavy metals in urban soils from southwest China. J Environ Sci. 24: 410–418. doi:10.1016/S1001-0742(11)60762-6.

Islam, A. R. M. T., Rakib, M. A., Islam, M. S (2015). Assessment of health hazard of metal concentration in groundwater of Bangladesh. Am Chem Sci J. 5: 41–49. doi:10.9734/ ACSj/2015/13175.

Fadigas, F. D. S., Nelson, M. B., Sobrinho, A. (2014). Estimation of reference values for Cadmium, Cobalt, Chromium, Copper, Nickel, Lead, and Zinc in Brazilian soils. Commun Soil Sci Plant Anal. 37: 945–959. doi:10.1080/00103620 600583885.

Trujillo-gonzález, J. M., Torres-mora, M. A., Keesstra, S. *et al.,* (2016). Heavy metal accumulation related to population density in road dust samples taken from urban sites under different land uses. Sci Total Environ. 553: 636–642. doi:10.1016/j.scitotenv.2016.02.101.

USEPA. (1989). Risk assessment guidance for superfund volume I human health evaluation manual (part A). I.

USEPA. (1996). Acid digestion of sediments, sludges, and soils. 1 - 12.

Zheng, N., Liu, J., Wang, Q. *et al.,* (2010). Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. Sci Total Environ. 408: 726–733. doi:10.1016/j.scitotenv.2009.10.075.

Lee, B., Kim, J. *et al*., (2006). As contamination in the abandoned metal mine areas, Korea. Environ Monit Assess. 2006: 233–244. doi:10.1007/s10661-005-9024-5.

Luo, X., Ding, J., Xu, B., *et al*. (2012). Incorporating bioaccessibility into human health risk assessments of heavy metals in urban park soils. Sci Total Environ. 424: 88–96. doi:10.1016/j.scitotenv.2012.02.053.

USEPA. (2002). Supplemental guidance for developing soil screening office of emergency and remedial response.

Li, Z., Ma, Z., Jan, T. *et al.* (2014). A review of soil heavy metal pollution from mines in China: pollution and health risk assessment. Sci Total Environ. 468-469: 843–853. doi:10.1016/j.scitotenv.2013.08.090.

Liu, Z., Fei, Y., Shi, H., Mo, L., & Qi, J. (2022). Prediction of high-risk areas of soil heavy metal pollution with multiple factors on a large scale in industrial agglomeration areas. *Science of the Total Environment*, *808*, 151874.

Tripathi, K. M., Kumar, D., & Mishra, S. (2024). Effect of Contamination of Heavy Metals in Soil and Its Mitigation Strategies: A Review. *International Journal of Plant & Soil Science*, *36*(7), 135–146.