*Original Research Article*

Heavy Metals Pollution in Ambient Air and Health Risk Assessment in Eket, Akwa Ibom State, Nigeria

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ABSTRACT

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| --- |
| **Aims:** Exposure to air pollution categorized by high levels of particulate matter and possibly toxic metals is of major concern to human health. The present study assessed the level of heavy metals in ambient air and related health hazards via ingestion, inhalation, and dermal absorption dose.  **Place and Duration of Study:** Sampling was performed at three selected junctions namely: Mobile matt (MM), Uqua junction (UJ), and Marina junction (MJ) using pre-weighed Petri dishes for 15 minutes.  **Methodology:** Heavy metal concentrations such as cadmium (Cd), Lead (Pb), manganese (Mn), arsenic (As), nickel (Ni), Copper (Cu) and chromium (Cr) were investigated using standard methods. lifetime cancer risk (ILCR), exposure concentration (EC), hazard quotient (HQ), and hazard index (HI) were used to evaluate the carcinogenic and non-carcinogenic health risks associated with exposure to measured heavy metals.  **Results:** Metal concentrations at MM, UJ, and MJ vary from 63 to 165 (mg/m3) for Cd, 314 to 823 (mg/m3) for Cr, 3 to 28 (mg/m3) for Pb, 284 to 412 (mg/m3) for Mn, 1 (mg/m3) for As, 73 to 202 (mg/m3) for Ni and 1 to 3 (mg/m3) for Cu, respectively, over a 15-minute average. All of the observed heavy metals' mean concentrations - Cr, Cd, Cu, Pb, Mn, As, and Ni are higher than the ATSDR reference concentration for inhalation. HI for kids at MJ indicated the possibility of non-CRs through ingesting. The probability of non-CRs by inhalation and skin exposure was demonstrated by HI for adults and children at MM, UJ, and MJ. While the ILCR values for Cd and Ni revealed moderate carcinogenic hazards from ingestion and inhalation of these metals at MM, UJ, and MJ, the ILCRing and ILCRinh values for Cr indicated substantial CRs from this metal. ILCRder values for Cr and Ni indicate low CRs for dermal exposure.  **Conclusion:** Continuous monitoring of metals and health risk assessment is recommended in the study area. |

*Keywords: [Heavy metals, health risks assessment, Eket)*

1. INTRODUCTION

Exposure to air contamination categorized by high levels of particulate matter and toxic metals is of major concern to human health. Because of its impact on human health, open-air pollution is a main issue. According to [1], long-term contact with air contamination can weaken the immune system and result in systemic cancer of the respiratory, reproductive, and neurological systems. Anthropogenic activity is one of the ways that air contaminants can reach the atmosphere. According to research reports, tons of air contamination have been released as a result of the industrial and urban sectors' rapid growth, thermal power plants, the expansion of farming employing more fertilizer and pesticides, and the uncontrolled usage of fossil fuels in numerous sectors [2 – 4].

Because of its harmful impacts on human health, respirable suspended particulate substances, a major contributor to air contamination have received a lot of consideration [5]. Respirable suspended particulate matter can originate from a variety of sources, comprising construction activities, manufacturing operations, vehicle emissions, dust and pollen from natural processes, noxious emissions released during waste burning, and suspended particulates matte [6, 1, 7, 8]. Because of the complex health dangers linked with exposure to these airborne contaminants, the presence of heavy metals in respiratory suspended particulate matter is frequently cause for concern.

Despite their low quantities, heavy metals namely mercury (Hg), cadmium (Cd), arsenic (As), nickel (Ni), lead (Pb), and others can be dangerous [9, 10, 11]. Anthropogenic activities that can release these metals into the atmosphere include mining, manufacturing processes, automobile releases, and fossil fuels burning [5, 11, 12]. People accidentally inhale this mixture of toxic gasses that contain heavy metal particles. Therefore, ongoing exposure to these metals raises serious health issues. It is well-recognized that contact with heavy metals and respirable dispersed particulate matter can have negative health effects. When respiratory suspended particulate matter particles are inhaled, they can penetrate the circulatory system, move deeply into the respiratory system, and possibly even make their way to the lungs' alveoli [13]. Inhalation can transfer toxic heavy metals straight to essential organs and tissues, leading to many detrimental health effects [14, 15]. Long-term exposure to heavy metals through respiratory dispersed particulate matter has been associated with some health issues, including the risk of cancer, cognitive decline, cardiovascular abnormalities, and respiratory diseases [4, 1]).

The International Agency for Research on Cancer (IARC) classified lead (Pb) and cobalt (Co) as group 2A carcinogens, but nickel (Ni), arsenic (As), chromium (Cr), and cadmium (Cd) were classified as group 1 carcinogens [16]. The ecosystem is at risk from these airborne heavy metals, and those who are exposed to them may experience adverse health impacts. These metals can lead to several serious health problems, including lung cancer, cardiovascular disease, high blood pressure, renal damage, reproductive problems, neurological disorders, asthma, and bronchitis. Furthermore, it has an impact on kids' cognitive development, which can lead to behavioral issues, difficulties in learning, and a lower intelligent quotient [17, 18, 19, 20]. The settlement of Eket is semi-urban. Eket's primary economic activities are farming (mostly for upland residents), fishing (for riverine and coastal residents), trading, okada riding, transportation, artisanship, and white-collar services. Owing to the presence of heavy metals in the solid and effluent wastes that are subsequently released into the atmosphere, these operations have the potential to significantly affect and stress air quality. There is a need to look at the connection between air quality and human health risks in the area because there aren't many studies relating the valuation of health risks in Eket, Akwa Ibom State, from anthropogenic activities there and ambient air contamination from heavy metals.

The current study's specific goals, considering the seriousness of the situation, are to: (i) measure the foci of specific heavy metals in ambient air at three specific locations in Eket; (ii) evaluate the potential health hazards related to these metals, including non-carcinogenic health indices (HQ and HI) and carcinogenic (CR); (iii) determine other lifetime cancer cases in Eket; and (iv) address health fears associated with air contamination and heavy metal contact pathways.

2. material and methods

**2.1 Location and Climate of the Study Area**

The Eket Local Government Area in Nigeria's Akwa Ibom State served as the study area. Eket is located eastward between longitudes 7 52' and 5 02' and between latitudes 4 33' and 4 45'. The two different seasons of Eket's tropical climate are November through March, with a brief dry spell in August typically interrupting the wet season. Eket experiences 23 to 31 degrees Celsius on average, with 3044 mm of precipitation.

**2.2 Sampling Procedures**

Sampling was performed at three junctions (Mobile Matt, Uqua junction, and Marina junction) using pre-weighed petri dishes for 15 minutes. After sampling, petri dishes were taken to Akwa Ibom State Ministry of Science and Technology Laboratory for analysis where the specimens were conserved in a fridge at 6 ºC until the chemical examination.

**2.3 Analysis of Heavy Metal***s*

The American Society for Testing and Materials (ASTM, 2010) and American Public Health Association (APHA), 20th Edition (2009) methods were employed in analyzing the samples.

**2.4 Health Risk Assessment**

**Heavy metal exposure from ingestion, inhalation, and the skin contact was utilized to fix the lifetime cancer risk and the non-carcinogenic health menace. The average daily dose (ADD) through eating (mg/Kg.day) (Equation 1), exposure concentrations through breath (EC) µg/m3 (Equation 2), and dermal absorption dose (DAD) (mg/kg-day) (Equation 3) are the three ways that human exposure is assessed [21, 22].**

**(1)**

**(2)**

**(3)**

**Table 1 presents the descriptions and the constant parameters involved in Eqs. (1, 2), and (3).**

**Table 1: Parameters values and definition applied for carcinogenic (CRs) and non-carcinogenic hazard (non-CRs) calculation**

|  |  |  |  |
| --- | --- | --- | --- |
| Factors/  Definitions | Values | | Sources |
| Children | Adults |
| Ci = The average concentration of HMs ((µg/m3) for EC, (mg/kg) for DAD and ADD) | Adopted from Previous study | Adopted from Previous s |  |
| IngR = Ingestion rate (mg/day) | 200 | 100 | [23] |
| EF = Exposure frequency (days/yr) | 180 | 180 | [22] |
| ED = Exposure period (Yrs) | 6 | 24 | [24] |
| ET = Exposure period (hrs/day) | 24 | 24 | [24] |
| AT = Mean lifetime (Days) | ED × 365  (non-carcinogens) | ED × 365  (non-carcinogens) | [24] |
| 70 × 365 (carcinogens) | 70 × 365 (carcinogens) |
| ATn = Mean lifetime (Hrs) | ED × 365 × 24  (non-carcinogens) | ED × 365 × 24 (non-carcinogens) | [24] |
| 70 × 365 × 24 (carcinogens) | 70 × 365 × 24 (carcinogens) |
| BW = Body weight (kg) | 15 | 70 | [24] |
| SA = Skin surface area (cm2) | 2800 | 5700 | [24] |
| AF = Adherence Factor (mg/cm2) | 0.2 | 0.07 | [24] |
| ABF = Absorption Factor | 0.1 (Pb), 0.03 (As), 0.001 (Cd), 0.01 (others) | | [22] |

***2.4.1 Non-Carcinogenic Health Risk***

Non-carcinogenic health peril examination of heavy metals was assessed through hazard quotient (HQ) which is determined based on Equations (4-6) [21, 22].

(4)

(5)

(6)

The HQ by inhalation, dermal contact and ingestion are denoted by the symbols , , and respectively. The heavy metal's reference concentration (mg/m3) and dose (mg/kg-day) are denoted by RfC and RfD, respectively. [22] provided the RfD and RfC values for the heavy metals under investigation. While hazard quotient values >1 suggest the possibility of negative health impacts, HQ values ≤1 show no major or tolerable risk [25]. The health dangers linked with exposure to several metals are predictable via the hazard index (HI). The following formula can be used to determine the hazard index (HI), which is the summation of the hazard quotients () of each metal "k" [21].

(7)

***2.4.2 Lifetime Cancer Risk***

Equations (8, 9), and (10) for dermal contact, ingestion, and inhalation respectively, can be used to approximate the lifetime risk of acquiring cancer owing to human exposure to these carcinogens (ILCR) [26].

(8)

(9)

(10)

Where, , , and are increasing lifetime cancer risks through dermal contact, ingestion, and inhalation correspondingly. SF is the Slope Factor (mg/kg-day)-1 and IUR is the inhalation unit risk ((µg/m3))-1 SF and IUR data for carcinogenic metals were obtained from the Office of Environmental Health Hazard Assessment [27], California. The ILCR can be grouped as very low, low, moderate, high, and very high. The collective ILCR for varying carcinogenic metals (i) is obtained by Equation (11) [28].

(11)

The collective ILCR for several carcinogenic metals should be kept lower than 10-4 [29].

3. results and discussion

**3.1 Concentrations of Heavy Metals**

Table 2 summarizes the concentration of selected heavy metals at Mobile Matt (MM), Uqua Junction (UJ), and Marina Junction (MJ) in mg/m3 compared with inhalation reference concentration (RfC) [30]. The 15-minute’ average concentrations of the metals at Mobile Matt, Uqua Junction, and Marina Junction range as: 314 – 823 (mg/m3) for Cr, 63 – 165 (mg/m3) for Cd, 1 – 3 (mg/m3) for Cu, 3 – 28 (mg/m3) for Pb, 284 – 412 (mg/m3) for Mn, 1 (mg/m3) at the three sampling locations for As, 73 – 202 (mg/m3) for Ni respectively. The average concentration of all the measured heavy metals Cr, Cd, Cu, Pb, Mn, As, and

Ni exceeds the inhalation reference concentration [30]. The key sources of heavy metals atmospheric pollution may include the resuspension of dust, traffic, incineration, industrial activities, combustion of fossil fuels, etc.

**Table 2 Smmary of Concentration of Heavy Metals (mg/m3)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Locations/  Parameters | MM  (mg/m3) | UJ  (mg/m3) | MJ  (mg/m3) | Inhalation Reference Concentrations (RfC) (mg/m3) [30] |
| Cr | 314 | 502 | 823 | 1.00E-04 |
| Cd | 63 | 87 | 165 | 1.00E-05 |
| Cu | 2 | 1 | 3 | 2.00E-05 |
| Pb | 3 | 16 | 28 | 5.00E-04 |
| As | 1 | 1 | 1 | 1.50E-05 |
| Ni | 202 | 73 | 123 | 1.40E-05 |
| Mn | 367 | 284 | 412 | 5.00E-05 |

**3.2 Health Risk Assessment**

Tables 3, 4, and 5 demonstrate the typical daily exposure dosages of heavy metals that are non-carcinogenic and carcinogenic by inhalation, ingestion, and skin contact linked to human exposure to harmful chemicals. Using the previously mentioned models, this study shows the probable non-carcinogenic and carcinogenic dangers of Pb, Cd, Cu, Cr, As, Ni, and Mn.

**Table 3. Average daily doses of non-carcinogenic and carcinogenic hazards of heavy metals through ingestion exposure**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Carcinogenic Risks** | | | **Non-Carcinogenic Risks** | | |
|  | **Adult** | | | **Adult** | | |
| **HMs** | **ADDing (MM)** | **ADDing (UJ)** | **ADDing**  **(MJ)** | **ADDing (MM)** | **ADDing (UJ)** | **ADDing (MJ)** |
| Cr | 7.58E-5 | 1.21E-4 | 1.98E-4 | 2.21E-4 | 3.53E-4 | 5.79E-4 |
| Cd | 1.52E-5 | 2.10E-5 | 3.90E-5 | 4.40E-5 | 6.12E-5 | 1.16E-4 |
| Cu | 4.80E-7 | 2.404-7 | 7.24E-7 | 1.40E-6 | 7.04E-7 | 2.11E-6 |
| Pb | 7.24E-7 | 3.86E-6 | 6.70E-6 | 2.11E-6 | 1.12E-5 | 1.97E-5 |
| As | 2.41E-7 | 2.41E-7 | 2.41E-7 | 7.04E-7 | 7.04E-7 | 7.04E-7 |
| Ni | 4.80E-5 | 1.70E-5 | 2.97E-5 | 1.42E-4 | 5.14E-5 | 8.66E-5 |
| Mn | 8.86E-5 | 6.85E-5 | 9.90E-5 | 2.58E-4 | 2.00E-4 | 2.90E-4 |
|  | **Children** | | | **Children** | | |
| Cr | 8.84E-5 | 1.41E-4 | 2.31E-4 | 1.03E-3 | 1.65E-3 | 2.70E-3 |
| Cd | 1.77E-5 | 2.45E-5 | 4.64E-5 | 2.07E-4 | 2.86E-4 | 5.42E-4 |
| Cu | 5.63E-7 | 2.81E-7 | 8.45E-7 | 6.57E-6 | 3.28E-6 | 9.86E-6 |
| Pb | 8.45E-7 | 4.50E-6 | 7.89E-6 | 9.86E-6 | 5.26E-5 | 9.20E-6 |
| As | 2.81E-7 | 2.81E-7 | 2.81E-7 | 3.28E-6 | 3.28E-6 | 3.28E-6 |
| Ni | 5.69E-5 | 2.05E-5 | 3.46E-5 | 6.64E-4 | 2.4E-4 | 4.00E-4 |
| Mn | 1.03E-4 | 8.00E-5 | 1.16E-4 | 1.20E-3 | 9.33E-4 | 1.35E-3 |

Table 4. Average daily exposure doses of non-carcinogenic and carcinogenic hazards of heavy metals through inhalation exposure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Carcinogenic Risks** | | | **Non-Carcinogenic Risks** | | |
|  | **Adult** | | | **Adult** | | |
| **HMs** | **ADDing (MM)** | **ADDing (UJ)** | **ADDing (MJ)** | **ADDing (MM)** | **ADDing (UJ)** | **ADDing (MJ)** |
| Cr | 5.30E-2 | 8.40E-2 | 1.39E-1 | 1.54E-1 | 2.47E-1 | 4.05E-1 |
| Cd | 1.00E-2 | 1.40E-2 | 2.70E-2 | 3.10E-2 | 4.20E-2 | 8.10E-2 |
| Cu | 3.00E-4 | 1.00E-4 | 5.00E-4 | 9.00E-4 | 4.00E-4 | 1.00E-3 |
| Pb | 5.00E-4 | 2.00E-3 | 4.00E-3 | 1.00E-3 | 7.00-E3 | 1.00E-2 |
| As | 1.00E-4 | 1.00E-4 | 1.00E-4 | 4.00E-4 | 4.00E-4 | 4.00E-4 |
| Ni | 3.40E-2 | 1.20E-2 | 2.00E-2 | 9.90E-2 | 3.60E-2 | 6.00E-2 |
| Mn | 6.20E-2 | 4.80E-2 | 6.90E-2 | 1.80E-1 | 1.40E-1 | 2.03E-1 |
|  | **Children** | | | **Children** | | |
| Cr | 1.30E-2 | 2.10E-2 | 3.40E-2 | 1.54E-1 | 2.47E-1 | 4.05E-1 |
| Cd | 2.00E-3 | 3.00E-3 | 6.00E-3 | 3.10E-2 | 4.20E-2 | 8.10E-2 |
| Cu | 8.00E-5 | 4.00E-5 | 1.00E-4 | 9.00E-4 | 4.00E-4 | 1.00E-3 |
| Pb | 1.00E-4 | 6.00E-4 | 1.00E-3 | 1.00E-3 | 7.00E-3 | 1.30E-2 |
| As | 4.00E-5 | 4.00E-5 | 4.00E-5 | 4.00E-4 | 4.00E-4 | 4.00E-4 |
| Ni | 8.00E-3 | 3.00E-3 | 5.00E-5 | 9.90E-2 | 3.60E-2 | 6.00E-2 |
| Mn | 1.50E-2 | 1.20E-2 | 1.70E-2 | 1.80E-1 | 1.40E-1 | 2.03E-1 |

**Table 5. Average daily exposure doses of non-carcinogenic and carcinogenic effects of heavy metals through dermal exposure**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Carcinogenic Risks** | | | **Non-Carcinogenic Risks** | | |
|  | **Adult** | | | **Adult** | | |
| **HMs** | **ADDing (MM)** | **ADDing (UJ)** | **ADDing (MJ)** | **ADDing (MM)** | **ADDing (UJ)** | **ADDing (MJ)** |
| Cr | 3.02E-6 | 4.83E-6 | 7.95E-6 | 8.82E-6 | 1.41E-5 | 2.31E-5 |
| Cd | 6.07E-8 | 8.38E-8 | 1.59E-7 | 1.77E-6 | 2.44E-7 | 4.63E-7 |
| Cu | 1.92E-8 | 9.63E-9 | 2.89E-8 | 5.62E-8 | 2.81E-8 | 8.43E-8 |
| Pb | 2.89E-7 | 1.54E-6 | 2.69E-6 | 8.42E-7 | 4.40E-6 | 7.80E-6 |
| As | 2.89E-8 | 2.89E-8 | 2.89E-8 | 8.43E-8 | 8.43E-8 | 8.43E-8 |
| Ni | 1.94E-6 | 7.03E-7 | 1.18E-6 | 5.67E-6 | 2.05E-6 | 3.45E-6 |
| Mn | 3.67E-6 | 2.73E-6 | 3.97E-6 | 1.03E-5 | 7.98E-6 | 1.15E-5 |
|  | **Children** | | | **Children** | | |
| Cr | 4.95E-6 | 7.92E-6 | 1.29E-5 | 5.78E-5 | 9.24E-5 | 1.51E-4 |
| Cd | 9.94E-8 | 1.37E-7 | 2.60E-7 | 1.15E-6 | 1.60E-6 | 3.03E-6 |
| Cu | 3.15E-8 | 1.57E-8 | 4.73E-8 | 3.68E-7 | 1.84E-7 | 5.52E-7 |
| Pb | 4.53E-7 | 2.52E-6 | 4.41E-6 | 5.52E-6 | 2.94E-5 | 5.15E-5 |
| As | 4.73E-8 | 4.73E-8 | 4.73E-8 | 5.52E-7 | 5.52E-7 | 5.52E-7 |
| Ni | 3.18E-6 | 1.15E-6 | 1.94E-6 | 3.71E-5 | 1.34E-5 | 2.26E-5 |
| Mn | 5.79E-6 | 4.48E-6 | 5.50E-6 | 6.75E-5 | 5.22E-5 | 7.58E-5 |

**3.2.1 Non-carcinogenic Risks (non-CRs)**

Tables 6, 7, and 8 present the findings of non-CRs associated with ingestion, dermal contact, and inhalation with heavy metals in Eket. The results revealed that the . This specified that the greatest exposure pathway to heavy metals in Eket was through inhalation. The HQingfor the studied heavy metals was lower than the acceptable level (HQ = 1) signifying no significant non CRs for children and adults in Eket at the three sampling locations from ingestion except for children at MJ which signifies significant non-CRs for children. HQinh for investigated heavy metals was above the safe level signifying significant non-CRs for children and adults at the three sampling sites from inhalation. The results showed that Cr, Cd, Ni, and Mn have harmful effects on adults and children through inhalation while Pb and As may not cause non-CRs. HQder exhibited the leeway of non CRs from exposure to Cr at UJ and MJ and non-harmful impacts from exposure to heavy metals.

Tables 6, 7, and 8 display the cumulative non-CRs, which were computed for ingestion, inhalation, and cutaneous routes and expressed as hazard index (HI). The probability of non-CRs from ingestion was shown by the HI data for children at MJ (HI = 1.48). Adults and children at MM, UJ, and MJ had HI values of 14.73, 12.06, 20.51, 15.33, 12.06, and 20.5, respectively, which indicated the probability of non-CRs from inhalation. Through dermal exposure, HI for children likewise demonstrated the probability of non-CRs at MM, UJ, and MJ (HI = 1.09, H = 1.75, and HI = 2.91). These results revealed that inhalation was the utmost damaging exposure pathway of heavy metals and Cr, Cd, Ni, and Mn were the key suppliers of hazard quotient in heavy metals in Eket.

**Table 6. Hazard Quotient for Non-Carcinogenic Risks (non-CRs) Associated with Heavy Metals via Ingestion Exposure**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Adult** | | | **Children** | | |
| **HMs** | **HQing (MM)** | **HQing**  **(UJ)** | **HQing**  **(MJ)** | **HQing (MM)** | **HQing**  **(UJ)** | **HQing**  **(MJ)** |
| Cr | 7.36E-2 | 1.17E-1 | 1.93E-1 | 3.43E-1 | 5.50E-1 | 9.00E-1 |
| Cd | 2.21E-2 | 6.12E-2 | 1.16E-1 | 2.07E-1 | 2.86E-1 | 5.42E-1 |
| Cu | 3.50E-5 | 1.76E-5 | 5.27E-5 | 1.64E-4 | 8.20E-5 | 2.46E-4 |
| Pb | 6.02E-4 | 3.20E-3 | 5.62E-3 | 2.81E-3 | 1.50E-2 | 2.62E-3 |
| As | 2.34E-3 | 2.34E-3 | 2.34E-3 | 1.09E-2 | 1.09E-2 | 1.09E-2 |
| Ni | 7.10E-3 | 2.57E-3 | 4.33E-3 | 3.32E-2 | 1.20E-2 | 2.00E-2 |
| Mn | 1.84E-3 | 1.42E-3 | 2.07E-3 | 8.57E-3 | 6.66E-3 | 9.64E-3 |
| HI | 1.07E-1 | 1.87E-1 | 3.20E-1 | 6.05E-1 | 8.80E-1 | 1.48 |

**Table 7. Hazard Quotient for Non-Carcinogenic Risks (non-CRs) Associated with Heavy Metals via Inhalation Exposure**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Adult** | | | **Children** | | |
| **HMs** | **HQInh**  **(MM)** | **HQInh**  **(UJ)** | **HQInh**  **(MJ)** | **HQInh**  **(MM)** | **HQInh**  **(UJ)** | **HQInh**  **(MJ)** |
| Cr | 1.54 | 2.47 | 4.05 | 1.54 | 2.47 | 4.05 |
| Cd | 3.10 | 4.2 | 8.1 | 3.1 | 4.2 | 8.1 |
| Cu | 2.25E-5 | 1.0E-5 | 2.5E-5 | 2.25E-5 | 1.0E-5 | 2.5E-5 |
| Pb | 2.85E-4 | 2.0E-3 | 2.85E-3 | 2.85E-4 | 2.0E-3 | 3.71E-3 |
| As | 2.66E-2 | 2.66E-2 | 2.66E-2 | 2.66E-2 | 2.66E-2 | 2.66E-2 |
| Ni | 7.07 | 2.57 | 4.28 | 7.07 | 2.57 | 4.28 |
| Mn | 3.6 | 2.8 | 4.06 | 3.6 | 2.8 | 4.06 |
| HI | 14.73 | 12.06 | 20.51 | 15.33 | 12.06 | 20.5 |

**Table 8. Hazard Quotient for Non-Carcinogenic Risks (non-CRs) Associated with Heavy Metals via Dermal Exposure**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Adult** | | | **Children** | | |
| **HMs** | **HQder**  **(MM)** | **HQder**  **(UJ)** | **HQder**  **(MJ)** | **HQder**  **(MM)** | **HQder**  **(UJ)** | **HQder**  **(MJ)** |
| Cr | 1.47E-1 | 2.35E-1 | 3.85E-1 | 9.63E-1 | 1.54 | 2.51 |
| Cd | 1.77E-1 | 2.44E-2 | 4.63E-2 | 1.15E-1 | 1.60E-1 | 3.03E-1 |
| Cu | 4.68E-6 | 2.34E-6 | 7.02E-6 | 3.06E-5 | 1.53E-5 | 4.60E-5 |
| Pb | 1.60E-3 | 8.38E-3 | 1.48E-2 | 1.05E-2 | 5.60E-2 | 9.80E-2 |
| Ni | 1.05E-3 | 3.79E-4 | 6.38E-4 | 6.87E-3 | 2.48E-3 | 4.18E-3 |
| Mn | 7.35E-5 | 5.70E-5 | 8.21E-5 | 4.82E-4 | 3.72E-4 | 5.41E-4 |
| HI | 3.32E-1 | 2.68E-1 | 4.46E-1 | 1.09 | 1.75 | 2.91 |

**3.2.2 Carcinogenic Risks (CRs)**

For the three carefully selected sites, the CRs of Cr (VI), Cd, Pb, and Ni by ingestion and dermal contact were computed and shown in Tables 9 and 11, while the CRs of Cr, Cd, Pb, As, and Ni via inhalation were computed and shown in Table 10. While the ILCR values for Cd and Ni were between 10-6≤ILCR<10-6, indicating low carcinogenic hazards from ingestion and inhalation of these metals at the three selected junctions MM, UJ, and MJ, the ILCRing and ILCRinh values for Cr were between 10-3≤ILCR<10-1, indicating high CRs from this metal. Low CRs were suggested by ILCRder values for Cr and Ni for cutaneous exposure, which fell between 10-6≤ILCR<10-4.

Significant carcinogenic hazards were suggested by the collective ILCR values for the investigated heavy metals, which were over the permissible levels of (1×10-4) for both adults and children through ingestion and inhalation paths (Tables 9 and 10). The cumulative ILCR values for the heavy metals under study were in the permissible range of (1×10-4) for both adults and children when exposed through the skin (Table 11), signifying that there are no appreciable carcinogenic hazards linked with cutaneous exposure to the metals under investigation. It is evident that while other metals exhibited low CRs, Cr accounts for the majority of cumulative ILCR through ingestion and inhalation. In terms of non-CRs and CRs in Eket, it can be said that the most harmful exposure to heavy metals is by ingestion and inhalation of Cr. Because it poses no risk of cancer, monitoring for Cr contamination in Eket's heavy metals should be given top priority.

Table 9. Carcinogenic Risks (CRs) Assessment of Heavy Metals via Ingestion Exposure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Adult | | | Children | | |
| HMs | ILCRs (MM) | ILCRs (UJ) | ILCRs  (MJ) | ILCRs  (MM) | ILCRs (UJ) | ILCRs  (MJ) |
| Cr | 3.10E-3 | 4.96E-3 | 8.11E-3 | 3.62E-3 | 5.78E-3 | 9.47E-3 |
| Cd | 9.27E-5 | 1.28E-4 | 2.37E-4 | 1.07E-4 | 1.46E-4 | 2.83E-4 |
| Pb | 6.15E-9 | 3.28E-8 | 5.69E-8 | 7.18E-9 | 3.82E-8 | 6.70E-8 |
| Ni | 4.03E-5 | 1.42E-5 | 2.49E-5 | 4.77E-5 | 1.72E-5 | 2.90E-5 |
| (∑  ILCRs) | 3.23E-3 | 5.10E-3 | 8.37E-3 | 3.77E-3 | 5.94E-3 | 9.78E-3 |

Table **10. Carcinogenic risks (CRs) assessment of heavy metals through inhalation exposure**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Adult** | | | **Children** | | |
| **HMs** | **ILCRs (MM)** | **ILCRs**  **(UJ)** | **ILCRs**  **(MJ)** | **ILCRs**  **(MM)** | **ILCRs (UJ)** | **ILCRs**  **(MJ)** |
| Cr | 4.45E-3 | 7.05E-3 | 1.16E-2 | 1.09E-3 | 1.76E-3 | 2.85E-3 |
| Cd | 1.80E-5 | 2.52E-5 | 4.86E-5 | 3.60E-6 | 5.40E-6 | 1.08E-5 |
| Pb | 6.00E-9 | 2.40E-8 | 4.80E-8 | 1.20E-9 | 7.20E-9 | 1.20E-8 |
| As | 4.30E-7 | 4.30E-7 | 4.30E-7 | 1.72E-7 | 1.72E-7 | 1.72E-7 |
| Ni | 8.16E-6 | 2.88E-6 | 4.80E-6 | 1.92E-6 | 7.20E-7 | 1.20E-6 |
| **(∑**  **ILCRs)** | 4.47E-3 | 7.07E-3 | 1.16E-2 | 1.09E-3 | 1.76E-3 | 2.86E-3 |

Table **11. Carcinogenic risks (CRs) assessment of heavy metals through dermal exposure**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Adult** | | | **Children** | | |
| **HMs** | **ILCRs (MM)** | **ILCRs**  **(UJ)** | **ILCRs**  **(MJ)** | **ILCRs**  **(MM)** | **ILCRs**  **(UJ)** | **ILCRs**  **(MJ)** |
| Cr | 1.23E-4 | 1.98E-4 | 3.25E-4 | 2.02E-4 | 3.24E-4 | 5.28E-4 |
| Cd | 3.70E-7 | 5.11E-7 | 9.69E-7 | 6.06E-7 | 8.35E-7 | 1.58E-6 |
| Pb | 2.45E-9 | 1.30E-8 | 2.28E-8 | 3.85E-9 | 2.14E-8 | 3.74E-8 |
| Ni | 1.62E-6 | 5.90E-7 | 9.91E-7 | 2.67E-6 | 9.66E-7 | 1.62E-6 |
| **(∑**  **ILCRs)** | 1.24E-4 | 1.99E-4 | 3.26E-4 | 2.05E-4 | 3.25E-4 | 5.31E-4 |

4. Conclusion

The average stages of Cd, Pb, Cu, Ni, Mn, As, and Cr are higher than the ATSDR inhalation reference values (RfC), according to the study. The findings demonstrated that inhalation was the principal method of contact with heavy metals in Eket, with EC>ADD>DAD.

Children's HI at MJ demonstrated the possibility of non-CRs through ingestion. The probability of non-CRs by inhalation and skin exposure was demonstrated by HI for adults and children at MM, UJ, and MJ. While the ILCR values for Cd and Ni suggested minimal carcinogenic risks from ingestion and inhaling of these metals at the three selected junctions MM, UJ, and MJ, the ILCRing and ILCRinh values for Cr indicated substantial CRs from this metal. ILCRder values for Cr and Ni indicate low CRs for dermal exposure.

Substantial carcinogenic hazards from contact with the examined metals are suggested by the collective ILCR values for the heavy metals under consideration for both children and adults through ingestion and inhalation paths. There are no appreciable carcinogenic hazards associated with exposure to the examined metals through the skin, according to the cumulative ILCR values for the heavy metals evaluated in both children and adults.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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