Ecological and health risk assessment of dissolved heavy metals in the urban road dust

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ABSTRACT
The purpose of this study was to determine the water-soluble concentrations of hazardous heavy metals in Zhengzhou city road dust in order to quantify the ecological and health risks. It was discovered that Cu (328.3 μg/l), and Zn (191.7 μg/l) were the metals with the highest concentrations, whereas Hg (0.24 μg/l), Cd (2.61 μg/l), and Pb (3.57 μg/l) were the metals with the lowest concentrations of heavy metals. Ecological risk assessment (RI) indicated the most abundant contaminant was Hg, followed by Cu and Cd, while five heavy metals (Cr, Ni, Zn, As, and Pb) fell into the no pollution or low pollution category. Inhalation health risks findings revealed that children were exposed to lead in industrial and commercial environments at levels that were not carcinogenic (HI > 0.1). Children and adults are both exposed to elevated Cu, Pb, and Zn levels in the commercial and residential areas of Zhengzhou.

1. Introduction
Heavy metals’ persistent, poisonous, and bio-accumulative properties, which make up a significant portion of the dust (0.02–5.7%), have received increased attention in recent years due to the dangers they pose to human health and the environment [1,2]. Human bioaccumulation of toxic heavy metals from urban dust, particularly in park areas frequented by locals and tourists alike, can lead to neurotoxicity and other health problems such as cardiovascular and cancerous disorders as well as kidney and bone diseases [4,5]. Pollution has accumulated in the environment as a result of rapid urbanization, industrialization, and land modification, which can lead to the introduction of heavy metals and eventually constitute an environmental health hazard to humans [6,7]. Anthropogenic activities, rather than natural sources, are the primary contributors to Hg emissions [8,9]. Because of the readily accessible Hg in pesticides, they can pollute water, soil, and air before becoming a component of road dust [10]. Thus, it is imperative to research the current status of heavy metal contamination in sediments and water, to determine ecological concerns, and to evaluate the likely sources [11].

Toxic metals attached to dust particles can enter the human body by inhalation, digestion, and dermal (skin) absorption [12,13]. Heavy metals found in road dust are a severe health hazard to humans [14]. Children are likely to be exposed to heavy metal particles when they inhale dust while sucking their fingers or mouthing non-food items [15]. A buildup of heavy metals in the environment can have a substantial impact on the ecological system. Heavy metals, on the other hand, have a negative effect on people who live in cities and suburbs. They can be mutagenic, teratogenic, and carcinogenic [16]. People who are exposed to heavy metals can lose different organelles and weaken their immune systems, which makes their bodies more susceptible to a wide range of illnesses [17,18]. Another thing that can happen is that plants can't do things like photosynthesis, transpiration, or respiration if they're contaminated with heavy metals [19]. Variations in human activities, land uses, and vehicle volumes in different city functional regions can cause significant spatial divergence in the ambient environment and contamination levels [2,20].

When it comes to determining whether something is carcinogenic or not, the hazard quotient (HQ), the cancer risk (CR), and the hazard risk (HR) are more important than the concentrations of heavy metals in the environment [21]. Many studies have illustrated the carcinogenic, teratogen, and mutagenic effects of various trace metals [16,18,21,22]. Therefore, it is of practical significance to investigate and assess the toxicity and health risk of metals [23]. Urban water contamination is caused by atmospheric dry and wet heavy metal deposition. Metals get into the air through industrial flue gas, fossil fuel combustion, automobile tyre wear, mining, adsorption on aerosol, and dust, and then, because of the weather, they become part of the surface or road. Another factor is rainfall, which influences runoff pollution on the surface and then
travels through the municipal pipeline, polluting the entire water system and contaminating the water with heavy metals. Similarly, Zhengzhou, the provincial capital of Henan, has a large population due to urbanisation. So, it was important to find out how different levels of heavy metals in road dust affect people's health in Zhengzhou. Thus, the study’s main goals are; (a) to determine the concentrations of dissolved heavy metals in road dust from several functional zones (b) to assess the potential ecological risk index (RI) posed by dissolved heavy metal buildup in road dust, and (c) to assess health risks for the elderly and children using the risk carcinogenic (CR) and Hazard Index (HI) approaches [22].

2. Materials and methods

2.1 Study area

Zhengzhou is the capital of Henan Province (34° 45’ 50.4” N, 11° 41’ 2.4” E) on the map shown in Figure 1. It is an important economic and transportation hub in central China, and it is also a logistical centre. In the expansive metropolis of the Central Belt, it serves as the province’s major city and is the province’s most populous city. The city is at the foot of the Funiu Hills, which are in the north of the country. To the west, it is flanked by upland terrain, while to the east, it is surrounded by topography that is moderate to low in elevation [24]. It occupies a total area of 1011.3 km2. The average amount of precipitation that falls each year is 629.7 mm. Most of it falls in the summer.

Because of its rapid growth as a metropolis in China’s central area, Zhengzhou is confronted with severe issues such as air pollution, rapid economic growth, and urban sprawl. Zhengzhou city’s PM$_{10}$ and PM$_{2.5}$ levels were on average 3.7 and 5.8 times higher than the general standard between 2014 and 2017, according to previous studies [25]. It was the seventh worst of 74 major cities in China when it came to air pollution in 2016. More than 70% of days in Zhengzhou’s air exceeded the pollution limit for PM$_{10}$ and PM$_{2.5}$. To make air pollution prevention and control more important and effective, the State Council of China’s Action Plan on Air Pollution Prevention and Control needs more information on how PM burns.

Figure 1. Research area of Zhengzhou.
2.2 Sample collection and laboratory analysis

Over the course of the study, 87 samples were collected from 29 distinct sites, representing a wide range of diverse uses, including education, industrial, parks, residential, and commercial. The dust sample was obtained employing a multi-point mixing strategy, and a massive chunk of the dust sample (150 g) was saved for further analysis and interpretation. All remaining plant debris, stones, or other material was screened out of the sample before it was ground up and passed through a 100-mesh screen. Then it was stored and allowed to air dry for at least a week before further analysis.

In order to assess the water-soluble concentration of heavy metals, dust samples were first dissolved in purified water. After that, we took the samples to the laboratory for further analysis, where the samples were kept at 20°C until these samples were analyzed. The samples were acidified with 10% HNO₃ before being placed in an ice bath. Method 6010B of the United States Environmental Protection Agency (US-EPA) Inductively coupled plasma atomic emission spectroscopy (ICP-AES) and Method 3010A were used for digestion and analysing the following heavy metals from the water soluble-contents of road dust; Cr, Ni, Cu, Zn, As, Cd, Hg, and Pb. A 100-ml sample of the well-mixed mixture was treated with 3 ml of strong nitric acid (Merck, HNO₃) before the beaker was covered with a watch glass. A hotplate was used to heat the solution until it evaporated to about 5 ml at 95°C without boiling. To complete the experiment, the beaker was allowed to cool before adding 3 mL of powerful nitric acid (HNO₃) and covering it with a watch glass.

Afterwards, the solution was refluxed at 95°C. We added more acid and kept doing the reflux until the look of the digestion didn’t change. 3 mL digestive solution, heated to 95°C to remove any precipitation or residuals created by evaporation, the sample digest was added to HCl (10 ml/100 ml final solution) for 15 minutes after cooling with 1:1-hydrochloric acid. With Milli-Q (analytical grade) and deionized water as diluents, the flask was cooled to room temperature and then transferred to a 125-ml high density polyethylene (HDPE) sample bottle for storage. Using the ICP-AES technique, trace metals were identified in sample solutions. The method detection limits employed in the investigation were: 0.4 for Arsenic, 0.09 for Cadmium, 2 for Chromium, 1 for Nickel, 0.002 for Hg, 0.6 for Copper, 2 for Lead, and 1 for Zinc. An ICP-AES analysis was used to look for certain elements in our study. The detection limits of the elements we looked for were set at the concentration level that correlates to an absorption intensity that was equal to 3 times the standard deviation of ten blank measurements. Each digestion load made blanks that were tested for the same things as the samples.

2.3 Ecological risk index (RI)

The risk index (RI) was calculated in order to evaluate the possible threats posed by heavy metals in surface sediments [26]. He was the one who came up with this index to assess the possible risk of heavy metal pollution in sediments. This strategy considers the toxicity of heavy metals as well as their cumulative effects on the aquatic ecosystem. The result was obtained after computing the total value of RI using the following formulas:

\[ RI = \sum_{i=1}^{n} E_i^l \]

\[ E_i^l = T_i^l \times C_i^l \]

\[ C_i^l = C_i^l / B_i^l \]

Where, \( E_i^l \) = potential ecological risk factor, \( T_i^l \) = response of toxic factor, \( C_i^l \) = contamination factor, \( C_{i-1}^l \) = average content of certain element, \( C_i^l \) = reference value of geochemical in the road dust. Toxic factor values were: Zn (1), Cr (2), Cu (5), Ni (5), Pb (5), As (10), Cd (30), and for Hg (40). Classification of RI has given in the Table 1.

2.4 Human health risk assessment

The evaluation approach can be used to determine if human exposure to polluted anthropogenic sources, such as heavy metals in water-soluble content, is non-carcinogenic or carcinogenic under present or future conditions. An assessment of the potential for non-carcinogenic and carcinogenic societal risks associated with heavy metals in water-soluble content should be conducted before a determination of the risk to health can be made. In the present context, people are divided into two classes based on variations in behaviour and physiology: adults and children. The main routes of exposure to the general population are direct dust intake, mouth-and-nose inhalation of particulates, or skin uptake. Adults have a significantly higher surface-to-volume ratio than children, who consume significantly more water and food per unit of body weight, grow at a faster rate, and exhibit more rapidly changing hand-to-mouth behaviours and physiology modifications than adults, which helps to explain the statistically significant difference in exposure risk between the two groups [27]. To assess the public

| Table 1. Classification of ecological risk index (RI). |
|-------------------------------------------------------|
| **Index** | **Category** | **Description** |
| Ecological Risk Index(RI) | Er ≤ 40; RI ≤ 150 | Low |
| 40 < Er ≤ 80; 150 < RI ≤ 300 | Moderate |
| 80 < Er ≤ 160; 300 < RI ≤ 600 | Considerable |
| 160 < Er ≤ 320; 600 < RI | High |
health concerns associated with urban road dust, individuals are classified as adults or children based on their exposure via one of four pathways: mouth ingestion, inhaling of resuspended particles via the nose, skin or eye contact with dust, or inhalation of mercury vapours [28]. The following equations were used to evaluate the probable non-carcinogenic and carcinogenic risks within each component in order to assess their respective risks:

### 2.4.1 Non-carcinogenic risk

The following equations were used to compute the non-cancer health risk values within each study ingredient through the use of the four exposure paths [28,29]:

$$AD_{ing} = C \times \frac{\text{IngR} \times EF \times ED}{\text{BW} \times AT} \times 10^{-6} \quad (5)$$

$$AD_{ing} = C \times \frac{\text{InhR} \times EF \times ED}{\text{PEF} \times \text{BW} \times \text{AT}} \times 10^{-6} \quad (6)$$

$$AD_{dernal} = C \times \frac{\text{SL} \times \text{SA} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \quad (7)$$

$$AD_{vap} = C \times \frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{VF} \times \text{BW} \times \text{AT}} \times 10^{-6} \quad (8)$$

Where, Average daily metal exposure via ingestion = $AD_{ing}$, Average daily metal exposure via inhalation = $AD_{inh}$, Average daily metal exposure via dermal contact = $AD_{dernal}$, Average daily metal exposure via vapors inhalation. Other parameters values have been given in the Table 2.

References [29–32]:

When four exposure pathways are considered, the hazard index (HI) is equivalent to the sum of the hazard quotients (HQs), which are computed by comparing the average daily exposure dose across each of the four paths to the reference dose for each element. The HI is used to estimate the non-carcinogenic risk buildup of a given element.

$$HQ = \frac{AD_{ing/inh/dermal/vap}}{RfD} \quad (9)$$

$$HI = \sum_{i=1}^{4} HQ_i \quad (10)$$

### Table 2. Values of parameters or factors used in assessing health risks.

| Factors | Unit | Children | Adults |
|---------|------|----------|--------|
| Ingestion rate of dust (IngR) | mg/day | 200 | 100 |
| Inhalation rate of dust (InhR) | m³/day | 10 | 20 |
| Exposure frequency (EF) | days/year | 180 | 180 |
| Exposure duration (ED) | Years | 6 | 24 |
| Body weight(BW) | Kg | 15 | 70 |
| Average time (AT) | non-carcinogenic | 2190 | 8760 |
| Particle emission factor (PEF) | m³/kg | 25.550 | $1.36 \times 10^3$ |
| Skin adherence factor for dust (SL) | mg/cm²/hour | 0.2 | 0.07 |
| Dermal absorption factor (ABS) | unit less | 2800 | 5700 |
| CarcinogenicRisk(CR) | non-carcinogenic | 0.001 |

If an element’s specific reference dose (RfD) limit is crossed, it indicates the likelihood that the element contaminant would have a long-term adverse effect on human health [33]. RfD is predicated on the notion that there are thresholds for various hazardous consequences, including cellular necrosis. RfD values are given in Table 3. If the HI 1 value is not substantial, the non-carcinogenic risk to human health is Values greater than 1 represent a substantial danger to the public of unfavourable non-carcinogenic effects.

### 2.4.2 Carcinogenic risk

For the cancer components As, Cr, Ni and Cd, the life average daily dosage (LADD) was calculated for inhalation with the following equation:

$$LADD = \frac{C \times EF}{AT \times PEF} \times \left( \frac{\text{InhR}_{child} \times ED_{child}}{\text{BW}_{child}} + \frac{\text{InhR}_{adult} \times ED_{adult}}{\text{BW}_{adult}} \right) \quad (11)$$

$$\text{CarcinogenicRisk(CR)} = LADD \times SF \quad (12)$$

When the above equations are combined with the values for the exposure variables, they produce an estimate of the “reasonable maximum exposure.” Instead of two cases of an average and upper bound exposure,
exposures were recommended to be evaluated for the same exposure case (both for present and future land use). The two studies, although approaching estimates with some uncertainty, are able to measure the possible range of uncertainty in these estimates. The upper bound estimate of exposure, however, may be above the range of possible exposure, and the lower bound estimate is below exposure levels that would be encountered by the vast majority of the population. In this work, the P-P plot of all element concentration levels revealed the logarithmic normal distribution by analysing heavy element concentrations in 87 dust samples from Zhengzhou using SPSS 22 software. As a result, an upper confidence limit (UCL) of a 95% confidence interval for the mean [34,35] was calculated using the following equation to assess the highest exposure that could reasonably be expected to occur at a site [36].

$$C_{95\%\text{UCL}} = \exp\left( \bar{X} + 0.5s^2 + \frac{s \times H}{\sqrt{n - 1}} \right)$$  (13)

Where, arithmetic mean of log-transformed data = $\bar{X}$, standard deviation of log transformed data = $s$, H-statistic = H [37] no. of samples = n, Children (INHCHILD, EDCHILD, and BWCHILD), and adults (INHAULT, EDADULT, and BWADULT) are all parameter values used to specify characteristics associated with children and adults Table 2. The slope factor (SF) of a specific carcinogen is represented by its values in the Table 3.

When exposed to heavy components in road dust, a CR of less than 10–6 indicates that there is no possibility of a carcinogenic risk; a CR of more than 10–4 indicates that a carcinogenic risk is quite likely. There must be some management strategies put in place when the CR is between 10–6 and 10–4. These strategies can help reduce the risk of cancer [38].

3. Results and discussions

3.1 Characteristics of dissolved heavy metal's in road dust

Using the water-soluble content to estimate heavy metal concentrations in road dust, it was observed that Cu, Zn, Ni, and As had the highest amounts, while Hg, Cd, and Pb had the lowest. The mean concentrations of the eight selected heavy metals declined typically in the sequence Cu > Zn > Ni > As > Cr > Pb > Cd > Hg in the urban dust water soluble sample from Zhengzhou. After further investigation, it was discovered that road sediment frequently contains significantly higher quantities of Cu, Zn, or Ni, and that their concentrations fluctuate significantly more between the different sampling locations. Table 4 shows the mean concentration values for all heavy metals (Cr, Ni, Cu, Zn, As, Cd, Pb, and Hg).

When the current study’s data was compared to previous studies in China, it was discovered that the Cr mean value of 26.70 g/l was not only the highest, but also approximately 13 times greater than Laoshan, Xiangshan, and 5 times greater than Dingzi. It couldn’t be compared because no one had measured Ni concentration, although the mean was 77.17 µg/l. Despite the fact that the Cu content in this sample was the highest, it was also much greater than that in previous reference studies. It was discovered that the quantities of Zn, As, and Cd were higher than those obtained in the cited study, at 191.7 µg/l, 47.10 µg/l, and 2.61 µg/l, respectively. However, the Pb concentration (3.57 µg/l) was higher than that of Dalian, Laizhou, and Dingzi, but lower than that of Laoshan, Xianshai, and Bohai, which were respectively 9.13 µg/l, 8.08 µg/l, and 9.55 µg/l. Except for the Xiangshan and Bohai trials, the Hg concentration was 0.24 µg/l, which was greater than all of the other research cited. Authorities and stakeholders in Zhengzhou must monitor the issue because background concentrations are greater. This demonstrates that the use of street cleaning and brushing devices, as well as the manner in which rainstorms are handled, have little impact on the spread of heavy metals.

### Table 4. Concentrations of heavy metals in the water soluble contents of road dust and reference areas (µg/l).

| Research Areas | Sites | Cr | Ni | Cu | Zn | As | Cd | Pb | Hg | References |
|---------------|------|----|----|----|----|----|----|----|----|------------|
| This Study    |      |    |    |    |    |    |    |    |    |            |
| Reference Areas | Zhengzhou, China | 26.70 | 77.17 | 328.3 | 191.7 | 47.10 | 2.61 | 3.57 | 0.24 | NA         |
|               | Laoxian, China  | 2.71 | NA | 4.50 | 5.71 | 1.75 | 0.76 | 9.13 | 0.02 | [39]       |
|               | Xiangshan, China | 2    | NA | 44.5 | 65.9 | 8.5 | 1.61 | 8.08 | 1.4  | [40]       |
|               | Dalian, China   | NA   | NA | 4.1  | 6.7  | 3.4 | 0.3  | 0.7  | 0.02 | [41]       |
|               | Laizhou, China  | NA   | NA | 15.88 | 2.37 | 0.38 | 2.07 | 0.094 |    | [42]       |
|               | Dingzi, China   | NA   | NA | 5.68 | 2.71 | 36.55 | 1.86 | 0.56 | 1.46 | 0.08       |
|               | Bohai, China    | NA   | NA | 7.17 | 9.0 | 4.02 | 0.68 | 9.55 | 0.36 | [44]       |
classified as RI (300–600) and are therefore regarded as extremely dangerous. It can be said that these three metals are prevalent in the water soluble content of road dust in Zhengzhou city and require the authorities’ immediate attention in order to address and protect the environment and human health from these harmful metals. No heavy metal’s RI value fell into the highest group of RI > 600, nor did any heavy metal fall into the lower category of RI (150–300), which indicates that either heavy metal is significantly high in risk or that heavy metal does not pollute the environment. With readings of 27.77, 43.04, 44.15, 39.46, and 23.41, chromium (Cr), nickel (Ni), zinc (Zn), arsenic (As), and lead (Pb) all fall into the same category of low risk or no pollution (RI 150). According to the ecological risk assessment approach, these five heavy metals were not among the most polluting contaminants and had no substantial effects on either the environment or human health, hence they were deemed to be quite safe. The order of RI values was Hg > Cu > Cd > Zn > Ni > As > Cr > Pb.

It is really crucial to discuss the scenario of these heavy metals in a single sample, which is an important reason for calculating the statistical data in this situation. It has been discovered that the findings of this RI calculation in a single sample are similar to the results that were seen for the mean values in the total sample. Among the highest-ranking elements in a single sample were mercury (537.41) and copper (501.36), both of which indicated significant contamination at the sampling site. The order of RI for maximum values was; Hg > Cu > Cd > Ni > Zn > As > Cr > Pb. The only difference in the order was that Ni was higher than Zn in this case.

### 3.3 Health risk assessment

When exposed to road dust contaminated with harmful metals, vulnerable groups with weakened immune systems, including children and patients, are at risk of developing serious health complications. The inhalation exposure of children and adults to the heavy metals under investigation in the water soluble contents of Zhengzhou road dust samples was used to determine the health risks associated with the heavy metals. Those with weaker immune systems, such as youngsters and the sick, are at significant risk of being harmed by the heavy metal-laden dust that pollutes roads. A health risk assessment technique developed by the United States Environmental Protection Agency (USEPA) was used to quantify the health risks associated with the examined metals, which included both non-carcinogenic and carcinogenic metals, for children and adults [30,32]. It was necessary to apply the model developed by the USEPA to compute health hazards because there were no local guideline values available. Health concerns posed by carcinogens and non-carcinogens when employing MDL_{inh} values for children and elderly exposition to harmful metals through relocated road dust, the Hazard Index (HI), and Hazard Quotient (HQ), were calculated. In this study, eight dangerous metals were chosen to look at for their possible health risks, both non-carcinogenic and carcinogenic.

According to the United States Environmental Protection Agency, if the HQ values are less than 1 \times 10^{-6}, the non-carcinogenic risk can be ignored [45] But if the values are sufficiently big and surpass 1 \times 10^{-4}, corrective steps should be taken [35]. The exposure parameters of eight heavy elements, which vary according to usage, were examined in terms of their HQ values. According to the results shown in Tables 6, 7, and 8, HQ_{inh} of all metals, HQ_{dermal} levels of Cr, and HQ_{vapor} of Hg were all greater than 110–4 for both children and adults.

Even more concerning is the fact that the HQ_{inh} value of As for children, as well as the HQ_{inh} value of Pb for adults and children, both surpassed 1 \times 10^{-2}. As per the HQ levels in different exposure routes, the non-carcinogenic exposure risk of Hg to humans were decreasing in the following sequence, according to the four exposure paths: inhalation through nose & mouth < dermal contact < ingestion < inhalation of vapors.

The findings indicate that reducing the possibility of heavy metal vapour pollution in the atmosphere via road sweeping, a cleaning process, is more difficult.

### Table 5. Statistical analysis of ecological risk assessment (RI).

| Quartile | Cr | Ni | Cu | Zn | As | Cd | Pb | Hg |
|----------|----|----|----|----|----|----|----|----|
| Min      | 13.14 | 15.19 | 140.84 | 19.24 | 33.01 | 190.26 | 14.84 | 292.90 |
| Q1       | 16.98 | 27.85 | 210.60 | 20.14 | 33.13 | 299.94 | 18.13 | 342.47 |
| Median   | 25.17 | 31.16 | 300.71 | 50.40 | 33.72 | 318.17 | 19.54 | 343.73 |
| Q3       | 39.08 | 60.20 | 500.17 | 50.64 | 44.36 | 367.95 | 25.00 | 517.07 |
| Max      | 44.49 | 80.79 | 501.36 | 80.34 | 53.09 | 369.97 | 39.54 | 537.41 |
| Mean     | 27.77 | 43.04 | 330.74 | 44.15 | 39.46 | 309.26 | 23.41 | 406.72 |

### Table 6. Calculations of HQ_{inh} for adults and children.

|        | Cr    | Ni    | Cu    | Zn    | As    | Cd    | Pb    | Hg    |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Adult  | HQ_{inh} | 95%   | 4.53E-03 | 2.07E-04 | 5.42E-04 | 3.60E-04 | 9.50E-03 | 1.61E-04 | 1.12E-02 | 6.48E-04 |
| Mean   | 3.91E-03 | 1.63E-04 | 4.65E-04 | 3.30E-04 | 9.12E-03 | 1.29E-04 | 1.12E-02 | 5.49E-04 |
| Min    | 1.50E-03 | 7.52E-05 | 1.33E-04 | 7.50E-05 | 4.86E-03 | 2.75E-05 | 3.83E-03 | 7.88E-05 |
| Max    | 2.93E-02 | 1.55E-03 | 2.78E-03 | 1.49E-03 | 1.41E-02 | 1.24E-03 | 3.20E-02 | 2.23E-03 |
| Children | HQ_{inh} | 95%   | 1.07E-02 | 4.56E-04 | 5.19E-03 | 3.39E-03 | 2.34E-02 | 4.10E-04 | 1.09E-01 | 6.16E-03 |
| Mean   | 9.28E-03 | 3.86E-04 | 4.47E-03 | 2.79E-03 | 2.13E-02 | 3.28E-04 | 9.53E-02 | 5.13E-03 |
| Min    | 3.51E-03 | 1.76E-04 | 1.16E-03 | 6.86E-04 | 1.13E-02 | 6.32E-05 | 3.60E-02 | 7.49E-04 |
| Max    | 6.82E-02 | 3.36E-03 | 2.60E-02 | 1.49E-02 | 3.33E-02 | 2.66E-03 | 3.06E-01 | 2.19E-02 |
Table 7. Calculations of HQ\textsubscript{inh} for adults and children.

|       | HQ\textsubscript{inh} | Cr  | Ni  | Cu  | Zn  | As  | Cd  | Pb  | Hg  |
|-------|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Adult | 95%                  | 3.83E-04 | 1.19E-06 | 3.26E-07 | 3.13E-07 | 3.79E-05 | 2.78E-05 | 1.31E-05 | 1.50E-06 |
|       | Mean                 | 3.31E-04 | 1.06E-06 | 2.58E-07 | 2.57E-07 | 3.62E-05 | 2.22E-05 | 1.23E-05 | 1.21E-06 |
|       | Min                  | 1.26E-04 | 4.61E-07 | 6.87E-08 | 6.19E-08 | 2.11E-05 | 4.68E-06 | 4.30E-06 | 1.93E-07 |
| Children | 95%                | 2.41E-03 | 8.94E-06 | 1.53E-06 | 1.26E-06 | 5.82E-05 | 1.93E-04 | 3.57E-05 | 5.53E-06 |
|       | Mean                 | 5.40E-04 | 1.71E-06 | 1.73E-06 | 1.72E-06 | 6.13E-05 | 3.70E-05 | 7.42E-05 | 8.30E-06 |
|       | Min                  | 2.06E-04 | 7.63E-07 | 4.49E-07 | 4.06E-07 | 3.27E-05 | 7.72E-06 | 2.80E-05 | 1.20E-06 |
|       | Max                  | 3.93E-03 | 1.40E-05 | 1.12E-05 | 8.30E-06 | 9.62E-05 | 3.13E-04 | 2.39E-04 | 3.60E-05 |

Table 8. Calculations of HQ\textsubscript{dermal} and HQ\textsubscript{vapor} for adults and children.

|       | HQ\textsubscript{dermal} | Cr  | Ni  | Cu  | Zn  | As  | Cd  | Pb  | Hg  |
|-------|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Adult | 95%                     | 4.79E-03 | 3.88E-03 | 1.20E-06 | 3.60E-05 |       |       |       |       |
|       | Mean                    | 4.79E-03 | 3.88E-03 | 1.20E-06 | 3.60E-05 |       |       |       |       |
|       | Min                     | 2.72E-03 | 2.20E-03 | 2.05E-03 | 2.34E-04 | 1.04E-02 |       |       |       |
| Children | 95%                   | 2.72E-03 | 2.20E-03 | 2.05E-03 | 2.34E-04 | 1.04E-02 |       |       |       |
|       | Mean                    | 2.72E-03 | 2.20E-03 | 2.05E-03 | 2.34E-04 | 1.04E-02 |       |       |       |
|       | Min                     | 2.72E-03 | 2.20E-03 | 2.05E-03 | 2.34E-04 | 1.04E-02 |       |       |       |

According to our findings for the vast majority of other elements, ingestion seems to be the most common route of non-carcinogenic potential exposure for both adults and children in Zhengzhou, followed by dermal contact through exposed skin and inhalation through the mouth and nose. According to prior studies, this conclusion is comparable to the one reached [29,33]. It emphasises the importance of maintaining good personal cleanliness, reducing the likelihood of hand-to-mouth conduct, and using correct skin protection measures when out in the sun, especially for youngsters who have rapid bone growth and are at higher risk of exposure [46].

In the non-carcinogenic health risk assessment, it was determined that different exposure routes had varying HI values and HQs based on the dust samples collected from various land use zones. Using statistical data from Table 9, the following was the sequence of all metals at risk in diverse functional domains, according to the evaluation made on the basis of the data in that table for adults and children: Commercial area > Industrial area > Residential area > Educational area > Parks and leisure areas. The non-carcinogenic risk scores for each heavy element were larger in magnitude for children when contrasted with those for adults in equivalent functional domains, but there was not a significantly different risk score for each heavy element in different land use zones. All heavy metals exposed to humans by urban dust had a maximum non-carcinogenic risk level hazard index greater than 0.1 in children living in industrial and commercial regions. Additionally, lead (Pb) is hazardous to human health even at low doses because it impairs neurodevelopment and other tissues [47]. On the other hand, elevated levels of lead in the blood can cause bone abnormalities [33], particularly in children, and may also have a harmful effect on the body’s neural synapses, kidneys, and

Table 9. Calculations of HI and CR for the various Landuse areas.

|            | Educational | Industrial | Residential | Commercial | Park & Leisure |
|------------|-------------|------------|-------------|------------|----------------|
|            | Adults | Children | Adults | Children | Adults | Children | Adults | Children | Adults | Children |
| HI         | 0.12-03 | 1.21-02 | 0.30E-02 | 0.12E-02 | 0.20E-02 | 1.30E-02 | 0.30E-02 | 1.30E-02 | 0.20E-02 | 1.30E-02 |
| Cr         | 0.88E-08 | 1.60E-07 | 0.12E-07 | 0.14E-07 | 0.20E-07 | 0.12E-07 | 0.14E-07 | 0.20E-07 | 0.12E-07 | 0.14E-07 |
| Ni         | 0.69E-10 | 0.63E-09 | 0.63E-09 | 0.63E-09 | 0.63E-09 | 0.63E-09 | 0.63E-09 | 0.63E-09 | 0.63E-09 | 0.63E-09 |
| Cd         | 0.28E-10 | 0.28E-10 | 0.28E-10 | 0.28E-10 | 0.28E-10 | 0.28E-10 | 0.28E-10 | 0.28E-10 | 0.28E-10 | 0.28E-10 |

According to Table 9, the following was the sequence of all metals at risk in diverse functional domains, according to the evaluation made on the basis of the data in that table for adults and children: Commercial area > Industrial area > Residential area > Educational area > Parks and leisure areas. The non-carcinogenic risk scores for each heavy element were larger in magnitude for children when contrasted with those for adults in equivalent functional domains, but there was not a significantly different risk score for each heavy element in different land use zones. All heavy metals exposed to humans by urban dust had a maximum non-carcinogenic risk level hazard index greater than 0.1 in children living in industrial and commercial regions.
brain tissues [36,484950]. Special prevention and healthcare are required for people, particularly children and teenagers who are exposed to contaminated commercial and industrial surroundings on a regular basis. As seen in the graph, adults and children both have the same tendency in the HI geographical distribution of each heavy element. When assessing the HI level of a specific heavy element at such a given concentration, the susceptibility of children to heavy elements is greater than that of adults [47]. In the middle of the study region, the HI values of Hg showed that both children and adults were exposed to a higher health risk, with a small discrepancy between them, with a 0.96 times lower threat to children than adults in the comparable areas. Minor variations were also seen in the HI levels of Cr, Ni, As, and Cd, with children being at 1.83, 2.21, 2.23, and 1.79 times more risk than adults in each of these elements, respectively.

Cd-related non-cancer risk was higher in northern Zhengzhou, while As-related non-cancer risk was higher in northern and western Zhengzhou. The Ni and Cr HI values were larger northwest of Zhengzhou, maybe because of the metal abundance in industrial areas, where robots are usually made using nickel hydrate and chromium alloys or nickel-cadmium batteries. The greatest significant differences were detected in the risk values for Cu, Zn, and Pb between children and adults, with levels that were 9.33, 9.25, and 9.22 times higher for children than for adults, respectively, representing an almost order of magnitude higher risk for children than for adults.

Copper, zinc, and lead, which are typically associated with the formation and use of vehicles, pose greater health risks for both children and adults in the urban central area of Zhengzhou, regardless of whether they are found in a commercial area, a residential area, or a park and recreation area [51]. In light of this phenomenon, it is reasonable to conclude that intense human activities such as commuter traffic and big crowds pose a significant non-cancer health risk. This discovery also demonstrates that heavy metals in roadside soils can have an impact on the heavy element content of the surrounding road sediments through a process known as diffusion [31].

The carcinogenic risk for toxic substances such as Cr, Ni, Cd, and As evaluated in this study showed that cancer risk for Ni, Cd, and As was negligible for the mean 6.53 ×10-10, 2.01 ×10-10, or 9.71 ×10-10 risk factors, which were correspondingly below 10−6 to 10−4 threshold values and considered acceptable, as shown in Table 9. But the greater value of As was a source of concern because it can result in a variety of adverse outcomes, including severe damage [62]. The cancer risk posed to the Zhengzhou population may have been lower than the figure of 10−6, but the cancer risks found in the industrial region were 8.50 ×10−7. Depending on their hazard index values, carcinogenic materials are divided into five functional categories. Chemicals such as Cr and Ni are the most significant cancer health threats, and they are concentrated in the industrial zone, followed by commercial, residential, and educational establishments, as well as parks, which all have equivalent HI values. Moreover, the use of chromium for preserving metal surfaces and building materials, including electrolysis, cells, polymers, and fertilizers, is widespread [56]. It is possible that the construction of commercial and educational structures, as well as the use of cells and polymers in residential regions, is responsible for the increased carcinogenic values of chromium found in commercial, educational, and residential areas. Cr exposure in industry should be factored into cancer risk assessments for workers. Some pollutants, such as polycyclic aromatic hydrocarbons, PM2.5, undiscovered heavy metals (such as Fe and Mn), or polluted areas, should be included in a comprehensive assessment of environmental risks.

Conclusions

Considerable metal pollution poses a serious hazard to public health, especially in highly populated metropolitan areas with extensive industrial facilities, heavy traffic, and a wide range of human-caused activities. In terms of heavy metal content, copper (Cu) and zinc (Zn) had the highest levels, but mercury (Hg), cadmium (Cd), and lead (Pb) were found to have the lowest amounts. The results of an ecological risk assessment (RI) revealed that mercury was the most abundant pollutant, followed by copper and lead, while five heavy metals (Cr, Ni, Zn, As, and Pb) were classified as having no pollution or low contamination. The health risks associated with inhalation were assessed using a methodology defined by the United States Environmental Protection Agency (USEPA) for both adults and children. The data indicated that children were exposed to lead at non-carcinogenic levels (HI > 0.1) in industrial and commercial settings. Zhengzhou’s business and residential sectors expose both children and adults to high Cu, Pb, and Zn levels. The presence of metal in the dust calls for quick and comprehensive pollution control and prevention efforts all over the city.

Data availability and materials

Laboratory results of this framework are collected from the physical sampling of the study area.

Disclosure statement

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References

[1] Wang M, Zhou X, Liu Y, et al. Trace and rare earth elements geochemistry of geothermal waters from the rehai high-temperature geothermal field in Tengchong of China. Appl Geopet. 2020;119:104639.

[2] Trujillo-González JM, Torres-Mora MA, Keesstra S, et al. Heavy metal accumulation related to population density in road dust samples taken from urban sites under different land uses. Sci Total Environ. 2016;553:636–642.

[3] Sezgin N, Ozkan HK, Demir G, et al. Determination of heavy metal concentrations in street dusts in Istanbul E-S highway. Environ Int. 2004;29(7):979–985.

[4] Kiciński A, Bożecki P. Metals and mineral phases of dusts collected in different urban parks of Krakow and their impact on the health of city residents. Environ Geochim Health. 2018;40(1):473–488.

[5] Huang J, Li F, Zeng G, et al. Integrating hierarchical bioavailability and population distribution into potential eco-risk assessment of heavy metals in road dust: a case study in Xiandao district, Changsha city, China. Sci Total Environ. 2015;541:969–976.

[6] Pan K, Wang W-X. Trace metal contamination in estuarine and coastal environments in China. Sci Total Environ. 2012;421:423–436.

[7] Chapman PM, Wang F, Janssen C, et al. Ecotoxicology of metals in aquatic sediments: binding and release, bioavailability, risk assessment, and remediation. Can J Fisheries Aquat Sci. 1998;55(10):2221–2243.

[8] Zhang Y, Cao S, Xu X, et al. metals compositions of indoor pm2.5, health risk assessment, and birth outcomes in Lanzhou, China. Environ Monit Assess. 2016;188(6):325.

[9] Guo W, Huo S, Ding W. historical record of human impact in a lake of Northern China: magnetic susceptibility, nutrients, heavy metals and OCps. Ecol Induc. 2015;57:74–81.

[10] Naderizadeh Z, Khademi H, Ayoubi S. Biomonitoring of atmospheric heavy metals pollution using dust deposited on date palm leaves in Southwestern Iran. Atmosfera. 2016;29:141–155.

[11] Song L, Gu D-G, Huang M-S, et al. Spatial distribution and contamination assessments of heavy metals in sediments of Wenzhou river network. Guan Pu Xue Yu Guang Pu Fen Xi. 2012;32(9):2540–2545.

[12] Charlesworth S, De Miguel E, Ordóñez A. A review of the distribution of particulate trace elements in urban terrestrial environments and its application to considerations of risk. Environ Geochem Health. 2011;33(2):103–123.

[13] Li F, Zhang J, Jiang W, et al. Spatial health risk assessment and hierarchical risk management for mercury in soils from a typical contaminated site, China. Environ Geochim Health. 2017;39(4):923–934.

[14] Faisal M, Wu Z, Wang H, et al. Geochemical mapping, risk assessment, and source identification of heavy metals in road dust using positive matrix factorization (PMF). Atmosphere. 2021;12(5):614.

[15] Goudarzi G, Daryanoosh SM, Godini H, et al. Health risk assessment of exposure to the middle-eastern dust storms in the iranian megacity of kermanshah. Public Health. 2017;148:109–116.

[16] Du Y, Gao B, Zhou H, et al. Health risk assessment of heavy metals in road dusts in urban parks of Beijing, China. Procedia Environ Sci. 2013;18:299–309.

[17] Zhang C, Qiao Q, Appel E, et al. Discriminating sources of anthropogenic heavy metals in urban street dusts using magnetic and chemical methods. J Geochem Explor. 2012;119-120:60–75.

[18] Maragkidou A, Arar S, Al-Hunaiti A, et al. Occupational health risk assessment and exposure to floor dust PAHs inside an educational building. Sci Total Environ. 2017;579:1050–1056.

[19] Qiu Y, Guan D, Song W, et al. Capture of heavy metals and sulfur by-fog in dust in urban Huizhou, Guangdong province, China. Chemosphere. 2009;75(4):447–452.

[20] Wang Q, Lu X, Pan H. Analysis of heavy metals in the resuspended road dusts from different functional areas in Xi’an, China. Environ Sci Pollut Res. 2016;23(19):19838–19846.

[21] Ma Y, Egodawatta P, McGree J, et al. Human health risk assessment of heavy metals in urban stormwater. Sci Total Environ. 2016;557-558:764–772.

[22] Rehman A, Liu G, Yousef B, et al. Characterizing pollution indices and children health risk assessment of potentially toxic metal(loid)s in school dust of Lahore, Pakistan. Ecotoxicol Environ Saf. 2020;190:110059.

[23] Faisal M, Wu Z, Wang H, et al. Human health risk assessment of heavy metals in the urban road dust of Zhengzhou metropolis, China. Atmosphere. 2021;12(9):1213.

[24] The State Council on the General Planning of Zhengzhou City Available online: http://www.gov.cn/zwgk/2010/08/23/content_1686432.htm (accessed on 2010 Oct 23).

[25] Misty G, Nan J, Wang S-B. Wang Shenbo analysis on the characteristics of air pollution and the impact of meteorological conditions in Zhengzhou from 2014 to 2017. Huan Jing Ke Xue. 2019;40(9):3856–3867.

[26] Hakansson L, Charlesworth S. An ecological risk index for aquatic pollution control-a sedimentological approach. Water Res. 1980;14(8):975–1001.

[27] Shi G, Chen Z, Bi C, et al. A comparative study of health risk of potentially toxic metals in urban and suburban road dust in the most populated city of China. Atmos Environ. 2011;45(3):764–771.

[28] Lin H, Zhu X, Feng Q, et al. Sources, and bonding mechanism of mercury in street dust of a subtropical city, Southern China. Hum Ecol Risk Assess. 2019;25(1–2):393–409.

[29] Weerasundara L, Magana-Aracuchi DN, Ziyath AM, et al. Health risk assessment of heavy metals in atmospheric deposition in a congested city environment in a developing country: Kandy city, Sri Lanka. J Environ Manage. 2018;220:198–206.

[30] USEPA (2017) Exposure Factors Handbook Chapter 5 (Update): soil and dust ingestion. U.S. EPA Office of Research and Development, Washington, DC, EPA/600/R-17/384 Available online: https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NCEA&dirEntId=337521 (accessed on 2021 Sept 10).

[31] Men C, Liu R, Xu F, et al. Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China. SciTotal Environ. 2018;612:138–147.

[32] USEPA.1989.Risk assessment guidance for superfund, vol. I: human health evaluation manual Risk Assessment Guidance for Super fund Volume I
[33] Mohmand J, Eqani SAMAS, Fasola M, et al. Human exposure to toxic metals via contaminated dust: bio-accumulation trends and their potential risk estimation. Chemosphere. 2015;132:142–151.

[34] Huang M, Wang W, Chan CY, et al. Contamination and risk assessment (based on bioaccessibility via ingestion and inhalation) of metal(loid)s in outdoor and indoor particles from urban centers of Guangzhou, China. Sci Total Environ. 2014;479-480:117–124.

[35] Kurt-Karakus PB. Determination of heavy metals in indoor dust from Istanbul, Turkey: estimation of the health risk. Environ Int. 2012;50:47–55.

[36] Safiur Rahman M, Khan MDH, Jolly YN, et al. Assessing risk to human health for heavy metal contamination through street dust in the Southeast Asian megacity: Dhaka, Bangladesh. SciTotal Environ. 2019;660:1610–1622.

[37] Gilbert RO. Statistical methods for environmental pollution monitoring. Richland WA: Pacific Northwest Lab. (PNNL); 1987.

[38] Wahab MIA, Razak WMMA, Sahani M, et al. Characteristics and health effect of heavy metals on non-exhaust road dusts in Kuala Lumpur. SciTotal Environ. 2020;703:135535.

[39] Wang X, Liu L, Zhao L, et al. Assessment of dissolved heavy metals in the Laoshan Bay, China. Mar Pollut Bull. 2019;149:110608.

[40] Zhao B, Wang X, Jin H, et al. Spatiotemporal variation and potential risks of seven heavy metals in seawater, sediment, and seafood in Xiangshan Bay, China (2011-2016). Chemosphere. 2018;212:1163–1171.

[41] Sun Q, Gao F, Chen Z, et al. The content and pollution evaluation of heavy metals in surface seawater in Dalian Bay, IOP Conf Ser Earth Environ Sci. 2019;227:062021.

[42] Lü D, Zheng B, Fang Y, et al. Distribution and pollution assessment of trace metals in seawater and sediment in Laizhou Bay. Chinese Journal of Oceanology and Limnology. 2015;33(4):1053–1061.

[43] Pan J, Pan JF, Wang M. Trace elements distribution and ecological risk assessment of seawater and sediments from Dingzi Bay, Shandong Peninsula, North China. Mar Pollut Bull. 2014;89(1–2):427–434.

[44] Peng S. The nutrient, total petroleum hydrocarbon and heavy metal contents in the seawater of Bohai Bay, China: temporal–spatial variations, sources, pollution statuses, and ecological risks. Mar Pollut Bull. 2015;95(1):445–451.

[45] USEPA (1996) Soil screening guidance: technical background document. EPA/540/R-95/128. office of solid waste and emergency response; Available online: https://nepis.epa.gov/Exe/ZyNET.exe/100025LM.TXT?ZyAction=D=ZyDocument&Client=EPA&Index=1995+Thru+1999&Docs=Query=&Time=&EndTime= &SearchMethod=1&ToCrestRestic=&ToC=&ToCEntry= &QField=&QFieldYear=&QFieldMonth=&QFieldDay= &IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D %3A%5Czyfiles%5CIndex%20Data%5C95thru99% 5CInt%5C00000000%5C10025LM.txt&User= ANONYMOUS&Password=anonymous&SortingMethod=he %7C&MaximumDocuments=1&FuzzyDegree= 0&ImageQuality=r75g8/r75g8/x150y150g16/ i425&Display=hpfr&DefSeekPage=x&SearchBack= ZyAction&Back=ZyAction&BackDesc=Results%20 page&MaximumPages=1&ZyEntry=1&SeekPage= x&ZyPURL (accessed on 2021 Sept 10).

[46] Chen H, Lu X, Li LY. Spatial distribution and risk assessment of metals in dust based on samples from nursery and primary schools of Xi’an, China. Atmos Environ. 2014;88:172–182.

[47] Ackah M. Soil elemental concentrations, geoaccumulation index, non-carcinogenic and carcinogenic risks in functional areas of an informal e-waste recycling area in Accra, Ghana. Chemosphere. 2019;235:908–917.

[48] Duan Z, Wang J, Xuan B, et al. Spatial distribution and health risk assessment of heavy metals in urban road dust of Guiyang, China. Nat Environ Pollut Technol. 2018;17:407–412.

[49] Zheng N, Liu J, Wang Q, et al. Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. SciTotal Environ. 2010;408(4):726–733.

[50] Škrbić BD, Buljovčić M, Jovanović G, et al. spatial variations and risk assessment of heavy elements in street dust from Novi Sad, Serbia. Chemosphere. 2018;205:452–462.

[51] Yang S, Li P, Liu J, et al. Source identification and health risks of potentially toxic metals in pyrotechnic-related road dust during Chinese New Year. Ecotoxicol Environ Saf. 2019;184:109604.