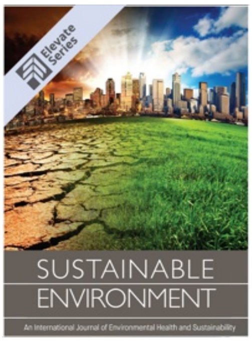

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Hidden hazards in urban soils: A meta-analysis review of global heavy metal contamination (2010-2022), sources and its Ecological and health consequences

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ABSTRACT

This study evaluated data from the literature on the presence of heavy metals for the period of 2010–2022 in the soils of 174 cities across the world. The range values (mg/kg) of Arsenic (As), lead (Pb), mercury (Hg), cadmium (Cd), chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn) and iron (Fe) were 0.95–152.00, 2.27–5780.00, 0.05–178.19, 0.03–298.90, 1.10–1631.43, 0.41–2560.00, 2.08 12,986.00, 1.14–3420.00 and 28.10 88,531.00. With the exception of Cr and Fe, all metals' average concentrations were higher than their average crustal values. A low to extremely high degree of contamination, presumably impacted by Pb, Hg, and Cd, was shown by the pollution indices. Urbanization, and industrial exhausts, are the main causes of high levels of pollution. Ecological risk showed that metals in urban soils pose a slight to highest environmental risk with mercury and Cd pose the highest ecological risk. A health risk assessment showed that some of the cities' residents are at risk for non-carcinogenic health risks (HI > 1), which are brought on by oral consumption and skin contact with metals in the soil. Inhabitants of these cities are exposed to carcinogenic health risk ($HI > 1 \times 10^{-4}$) which are triggered by ingestion and contact with heavy metals in soils. Therefore, frequent monitoring of heavy metals in urban soils should be carried out to forestall the environmental and health risks associated with them which is the main goal of this review.

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Carcinogenic health risks; cities; ecological risks; heavy metals; non-carcinogenic health risks Urban soils

1. Introduction

The issue of pollution is widespread, and it significantly impacts people's health (Khan & Ghouri, 2011). Public awareness has been raised by the alarming extent to which industrial effluents, vehicles, and megacities contribute to pollution (Adelekan & Abegunde, 2011; Begum et al., 2009; Mao et al., 2010; Qin et al., 2023). High pollution harms the ecosystem and the health of people, animals, and vegetation (Khan & Ghouri, 2011). Numerous ailments, including those that affect not just the elderly but also children and the active, as well as all plants and animals, are brought on by pollution (Adewumi, 2022; Calkins, 2008; Combs, 2013; Delbari & Kulkarni, 2011; Gong et al., 2010; Ijeoma et al., 2011; Milenkovic et al., 2015; Khalid et al., 2020; Laidlaw et al., 2018; Soltani-Gerdefaramarzi, 2021). Over twenty-one million individuals globally suffer severe pollution, which has now gotten worse due to overcrowding, according to a WHO assessment (Pain, 2008). Due to the fact that 1.3 billion people are exposed to high quantities of heavy metals, between five and ten million people, typically children, die from severe metal-related diseases every year (Ahuja, 2009).

The environment could be described as the physical setting in which people live. These elements include the land, water, and atmosphere of the Earth, as well as any part or feature of the first two elements listed here, their interactions, and the chemical, physical, aesthetic, and cultural traits and conditions of those previously mentioned that have an effect on human health and well-being. It is also distinguished by various factors that affect its behavior and inherent worth (Atapattu, 2007). Microorganisms, animals, and plants all live in or act within ecosystems. It is composed of the Earth's atmosphere, ocean, and surface. The four spheres—the lithosphere (land), the atmosphere (air), the hydrosphere (water), and the biosphere (living things)—that make up the Earth's system all coexist harmoniously with one another (Wong, 2013).

The biosphere, which houses all living things, is the most important environmental factor. This is where living things (animals and plants) interact with one another and their non-living surroundings (soil, air, and water). Sadly, in recent centuries, industrialization and globalization have damaged natural environments and their ability to support life. This has resulted in

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factors that jeopardize the general health and values of the ecosystem (Atapattu, 2007).

The environment might be polluted or contaminated. Although contamination may also be a kind of pollution with negative environmental repercussions, pollution is different from contamination. According to research, pollution is the active or passive discharge of energy or materials into the environment by people, which has the detrimental effects of harming living things, endangering human health, impeding environmental activities, deteriorating the general quality of a living thing in the environment, and reducing amenities (Wong, 2013). On the other hand, contamination is the existence of excessive amounts of environmental toxins above what is considered typical for the region and the organism. All living things, including plants and animals, suffer from environmental pollution, which is the accidental modification of the physical, chemical, and biological qualities of the air, water, and soil (Wong, 2013). Chemical molecules or materials, such as sound, heat, or light, can be pollutants. In addition, naturally occurring contaminants and alien substances or energies can be pollutants, which are pollution ingredients (Atapattu, 2007).

Urban development and industrialization have made soil contamination a serious worldwide environmental problem in recent years due to the growing global population (Soleimani et al., 2018). Despite the fact that there are many causes of heavy metal pollution, urbanization and industrialization are the two factors that have contributed to the rise in the concentration of heavy metals in the environment. Heavy metals are carried in runoff from urban, industrial, and municipal regions. Most of such metal risks accumulate in soil, sediment, and water bodies, and some find their way into dust (Musilova et al., 2016). Even though heavy metals are only found in trace levels in soil, they are extremely dangerous and pose serious threats to human health as well as the health of other living things. This is due to the fact that a metal's level of toxicity changes depending on a number of factors, such as the species to which it is exposed, its biological role, its type, and the amount of time that the organisms are exposed to the metal. Food webs and food chains serve as symbols for the interactions between organisms. As a result, all species are impacted by heavy metal poisoning because heavy metal concentrations rise in the food chain. Humans, an example of an organism that feeds at the top of the food chain, are more vulnerable to significant health issues (Lee et al., 2002).

Having heavy metals in the ecosystem has a lot of adverse effects. All four spheres of the environment—the hydrosphere, lithosphere, biosphere, and atmosphere—are impacted by such effects. As a result, health and mortality issues arise until the effects are addressed and food networks are disrupted (Lepp, 2012). Furthermore, since more heavy metals are being used and processed in various processes to fulfill the demands of the world's rapidly expanding population, contamination by heavy metals is now a significant cause for concern on a global scale. Heavy metal contamination primarily affects the ecosystem's soil, water, and air (Musilova et al., 2016).

Emissions from sources and activities that cause heavy metal soil pollution, including industrial processes, high-metal waste disposal, mining tailings, leaded paints and gasoline, sewage sludge, animal manures, wastewater irrigation, pesticides, coal combustion residues, petrochemical spills, and insecticides Heavy metals discharged into the environment by the preceding anthropogenic activities have been reported to be primarily absorbed by soils. Because the majority of heavy metals are not biodegradable and do not undergo microbial or chemical breakdown, their total levels stay in the environment for a very long period after being released (Lepp, 2012). Heavy metal pollutant levels in sediment and soil are a severe problem because they can enter food chains and disrupt the entire ecosystem. Even though organic pollutants have a potential for biodegradation, the accumulation of heavy metals in the environment slows down their biodegradability, which doubles the amount of environmental pollution caused by both organic and inorganic pollutants. Risks from heavy metals to people, animals, plants, and environments come in many forms. These include direct intake, food chain, plant absorption, consumption of polluted water, and changes to the pH, color, porosity, and chemistry of the soil, all of which affect the soil quality (Musilova et al., 2016).

Despite a precise definition, heavy metals are described in the literature as naturally occurring elements with high atomic weights and densities five times greater than water (Atapattu, 2007). Due to their hazardous nature, environmental scientists have given heavy metals the most attention among all contaminants. Natural waterways typically include minimal heavy metals, but most are dangerous even at low doses (Herawati et al., 2000). Highly poisonous metals, even in small amounts, include selenium, zinc, cobalt, chromium, Mercury, nickel, cadmium, lead, and arsenic. A growing number of industries are releasing their metal-containing waste into the soil without sufficient treatment, which is a cause for concern regarding the level of heavy metals in our resources (Salomons et al., 2012). When heavy metals build up in soft tissues without being metabolized by the human body, they become poisonous. In agricultural, industrial, manufacturing, pharmaceutical, or residential areas, they may come into contact with people and enter the body through the skin, air, water, food, etc. Adults frequently become exposed through industrial exposure. The most frequent method of exposure for kids is ingestion. The world and its resources are being polluted by natural and human activities, releasing more pollutants than the environment can tolerate (He et al., 2005).

Heavy metals may be produced by both natural and manmade processes, which can lead to different environmental media (soil, water, air, and their interfaces). Numerous investigations have identified certain heavy metals' natural sources. Natural discharges of heavy metals take place under various and specific environmental circumstances. Rock weathering, forest fires, sea-salt spray, volcanic eruptions, and storm soil particles are a few examples of these emissions. Metals may be released from their endemic spheres and other environmental compartments by natural weathering processes. Hydroxides, oxides, sulfides, sulfates, phosphates, silicates, and organic compounds are all heavy metals. Copper (Cu), zinc (Zn), Mercury (Hg), arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni), and lead (Pb) are the most abundant heavy metals. Although the aforementioned heavy metals are present in minute amounts, they represent a serious risk to both human and animal health (He et al., 2005).

Pollutants are also released into various environmental compartments through runoff, wastewater treatment, mining, agriculture, and industrial operations. It has been observed that artificial sources of heavy metals surpass the natural rates for several elements. Most of the naturally occurring metals in wind-blown dust come from industrial regions. The combustion of fossil fuels releases tin, Mercury, nickel, selenium, and vanadium, as well as other vital artificial sources such as metal-working, which releases zinc, copper, and arsenic. Pesticides, which release lead and arsenic, and automotive exhaust, which release lead and mercury, Human activities have been shown to contribute more to environmental deterioration since products are frequently produced to meet the demands of an enormous population (Trefry, 1977).

Urban soil pollution, including its generation and modification processes, the vertical and horizontal geographical distribution of soil characteristics, and the ability to predict such property distributions so that they may be mapped, have all attracted more attention in recent years (Diaz Rizo et al., 2011; Howard & Shuster, 2015; Lehmann & Stahr, 2007: Li et al., 2017; Wu et al., 2020). These research findings reinforce the idea put forth by scientists to view soil as a human-natural body because urban soils are strongly impacted by anthropogenic activities (Richter et al., 2011).

The anthropogenic causes that result in the wide variety of urban soils can introduce a variety of contaminants that could be harmful to human health. For instance, because of the proximity of kids to Some of the sources of the contamination now identified in urban soil include the combustion of leaded gasoline, the use of smelting and other industrial processes, the recycling and disposal of waste, lead-based paints, the application of lawn chemicals, and even the historical use of pressure-treated wood in playground equipment (Gardner et al., 2013).

Urban soils carry the burden of past activities' contamination, even though active contamination has significantly decreased in many developed nations (Filippelli & Laidlaw, 2010). On the other hand, contamination is still occurring actively in many developing countries. Furthermore, given the significant proportion of people who live in urban areas (approximately 54% of the world's population as of 2014 and increasing, particularly in developing countries; WHO, 2016), there is a high risk of adverse health effects from exposure to polluted soil in the urban environment. Recent years have also seen the emergence of a flourishing urban gardening movement (Philpott et al., 2014), which provides containment for food to enter the human food chain through soil-plant interactions (Beniston et al., 2016).

Since year 2010 the world's developments have been on the increase, especially with developing countries over performing in technological and economic advancement (UTCTAD, 2022). The rates of development in many cities within this time frame are more than the preceding years. These advancements have significantly contributed to the degrading of soils, especially in cities across the world. Many studies have revealed the level of urban soil degradation across the world. Silva et al. (2021) revealed that cadmium and nickel in the soils of Lisbon, Portugal were above the average crustal values which implied pollution from anthropogenic sources. Wieczorek et al. (2020) evaluated heavy metals contents in urban soils that are impacted by industrial activities. Their study showed that most urban soils were highly polluted by toxic metals. Likewise, Mehmood et al. uncovered that soils of Faisalabad city, Pakistan were significantly polluted by heavy metals by human activities from local industries. These evidences showed that urban soils in many parts of the world are being impacted by human activities that releases heavy metals into them. Also, increase in soil pollution portend danger to the ecosystem and human health if not urgently tamed. To stall these consequences, there is a need to regularly monitor environmental degradation to prevent the outbreak of preventable diseases. It is also important to review the status of soil pollution in urban areas as cities continue to expand due to increased rural-urban migration. Therefore, this study was carried out to analyze metadata on heavy metal concentrations in soils in megacities across the world that was obtained from published literature. The objectives of the study were to (1) extract data on the amount of heavy metals in urban soils across major megacities in the world as published in recognized journals; (2) compare the concentrations of these metals to acceptable international standards; (3) evaluate the extent of urban soil pollution using acceptable models; (4) assess the degree of ecological risks impacted by these metals; and (5) determine the extent to which the health of inhabitants of these cities may be affected by heavy metals in the soils. To achieve these set goals, data from literatures focusing of heavy metals analysis in soils of selected urban areas across the world were extracted following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) method. These data were subjected to eligibility tests to ensure they meet the inclusions criteria. All data that passed the eligibility tests were further subjected to basic statistical and detailed geochemical data analysis such as contamination, ecological and human health risk assessments.

2. Materials and methods

2.1. Study approach

The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) approach was employed in this study, as outlined in Figure 1. We initially phrased the study issue as a question, as follows, in order to find all published papers in this context for this systematic review: What is the present degree of ecological and human health risk assessment of heavy metals in the soils of various cities across the world? How many publications have been published on contamination? Following, we defined our search strings based on the specified framework. Accordingly, the following components were considered, each of them containing one or more keywords related to our search as follows: 'contamination' OR 'contaminant' OR 'pollution' OR 'pollutant' OR 'heavy metals' OR 'soil contamination' OR 'soil contaminants' OR 'soils' OR 'ecological health risk' OR 'heavy metals in urban soils OR contamination of soils in cities' OR 'assessment of heavy metals in cities'. Two databases, Scopus and PubMed, were used to search for articles based on the above-mentioned strategies and only in English between the years 2010 and 2022 in 174 cities across the world (Figure 2).

2.2. Screening and eligibility criteria

Using the PRISMA method, the bibliographic information of all retrieved articles was downloaded. Then, we deleted duplicate papers. After that, some inclusion and exclusion criteria were defined by the research team and performed to screen and qualify the articles. We considered the following criteria for inclusion:

(1) Were the studies published as original papers?
(2) Were the studies published only in English?
(3) Were they published between 2010 and 2022?
(4) Did the studies report at least three of the heavy metals selected for inclusion?

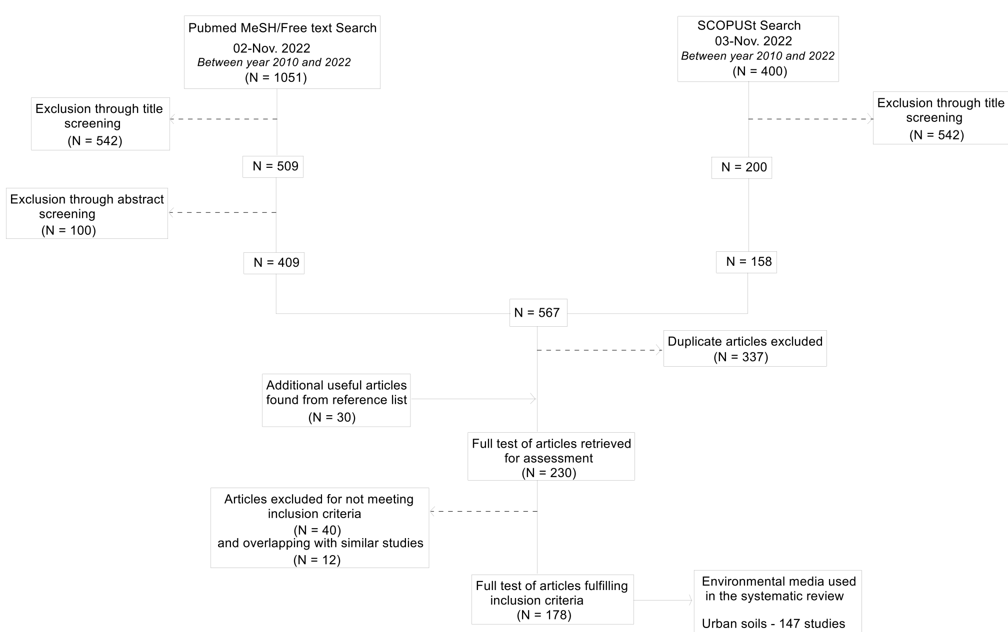

Figure 1. PRISMA techniques used in this research.

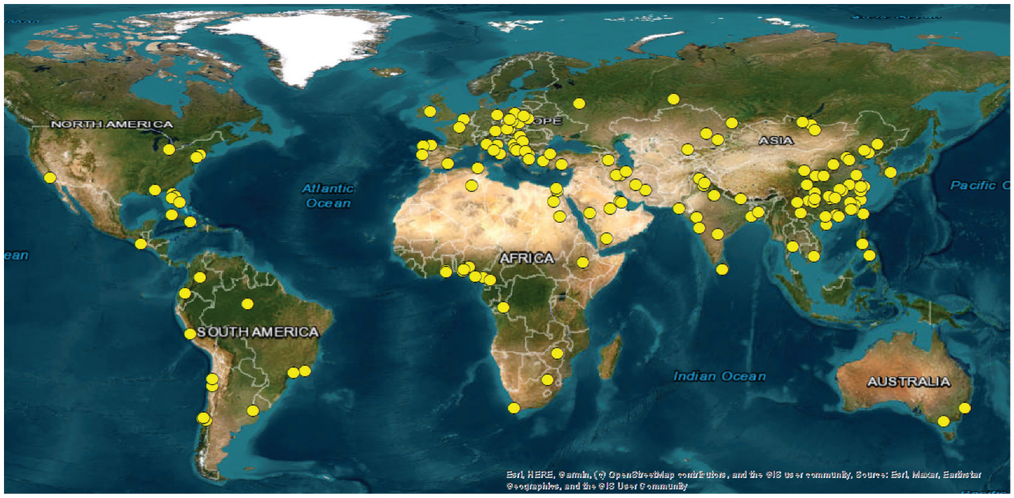

Figure 2. Location of cities across the world reported in this study.

After all these criteria had been outlined, double-blind checking was done by two independent reviewers on the parts of Title, Abstract, and Keywords. Whenever it was not possible to select the appropriate articles based on the above-mentioned criteria, we referred to the full text, and the final decision was made after reading the full text of the article. Finally, the selected articles were carefully reviewed in full text, and the information was extracted from them and entered in an Excel file. The Excel data contained information such as the name of the continent, country, cities, and metals under investigation (arsenic, lead, mercury, cadmium, chromium, cobalt, nickel, copper, zinc, and iron). All data were screened by using the minimum, maximum, and average concentrations of heavy metals obtained for the data extracted for this study. Furthermore, sources of heavy metals in soils of each city were extracted from the literatures and included in the study.

2.3. Assessment of heavy metal contamination in urban soils

2.3.1. Index of geoaccumulation (igeo)

The Igeo was used to evaluate metal enrichment over baseline or background values as described by to determine the degree of contamination of a certain metal in soils (Adewumi et al., 2022; Muller, 1969). Equation 1 was used to construct the Geo-accumulation index.

$$I_{geo} = log_2 \frac{C_n}{1.5 \times B_n} \quad (1)$$

Cn is the metal concentration in the sample, Bn is the metal concentration in the background sample, and the constant 1.5 is included to reduce the impact of any potential changes in the background values that may be caused by lithologic variances in the samples. In this study we used the average crustal values as listed by (Rudnick & Gao, 2003) as background values. Loska et al. (2004) provided the following interpretation for the Igeo: Igeo < 0 (practically unpolluted), 0 < Igeo < 1 (unpolluted to moderated polluted), 1 < Igeo < 2 (moderately polluted), 2 < Igeo < 3 (moderately to strongly polluted) 3 < Igeo < 4 (strongly polluted) 4 < Igeo < 5 (strongly to extremely polluted) and Igeo > 5 (extremely polluted).

2.3.2. Contamination factor (CF) and contamination degree (CD)

The Hakanson (1980) approach was used to analyze soil contamination, and Equation 2's contamination factor was used. All four classes are acknowledged, and the single element index is called the CF.

$$CF = {}^{Metal\ concentration\ in\ soil}/_{Concentration\ of\ metal\ in\ background\ soils.} \quad (2)$$

The following categories apply to the CF: CF < 1: low contamination; 1< CF < 3: moderate contamination; 3 < CF < 6: considerable contamination; CF ≥ 6: very high contamination.

The CD of the environment is represented by the total of the contamination factors for all investigated materials. The CD aims to quantify the level of overall contamination in surface layers at a specific sampling location. Equation 3 displays the formula for computing the CD.

$$C_d = \sum_{i=1}^{n} \times C_f^i \quad (3)$$

where Cd and Cf stand for contamination degree and factor, respectively. Low contamination is denoted by a

CD < 6, whereas substantial contamination is denoted by a 6<CD < 12. Additionally, CD > 24 represents a high level of contamination, whereas 12>CD > 24 reflects a significant level of contamination.

2.3.3. Pollution Load Index (PLI)

The PLI, which is used to evaluate environmental quality, is defined as the ratio of element concentration in the research to the background content of the abundance of chemical elements in the continental crust. The equation 4 below, developed by Tomlinson et al. (1980) and used by Adewumi et al. (2020) was used to calculate the PLI for the soil samples.

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots CF_n)^{1/n} \quad (4)$$

The CF is contamination factor of each metal while the n is the total number of metals included in the analysis.

The PLI of each metal is categorized as low ($P \leq 1$), intermediate ($1 < PI \leq 3$), or high ($PI > 3$), according to Adewumi et al. (2020).

2.4. Assessment of ecological risk of heavy metals in urban soils

The ecological risk index (ERI) (Equation 5) provided by was used to assess the ecological dangers associated with metals (Wang et al., 2015)

$$ERI = T_R^i \times C_F^i \quad (5)$$

Where CF is the pollution of a single element factor, which is also the contamination factor, and ERI is the potential ecological risk of a single element; TR is the toxic-response factor. For some of the metals utilized in the study, the toxic-response factors were Zn = 1, Cr = 2, Cu = 5, Pb = 5, cadmium (Cd) = 30, and Ni = 5. The risk index (RI), which is the total of the ecological risk assessment, is created with the aid of the data from Equation 6.

$$RI = \sum_{i=1}^{m} \times E_R^i \quad (6)$$

Low ecological risk is implied when ER is between 40 and 150; moderate ecological risk is implied when ER is between 40 and 80 and RI is between 150 and 300. A 160≤ER < 320 denotes considerable ecological risk, whereas a 80≤ER < 160 and 300≤RI ≤ 600 suggests significant ecological risk. A very high ecological risk is indicated by an ER ≥ 320 and RI > 600.

2.5. Heavy metals in urban soils: Risk assessment to human health

Based on suggestions from many American papers, the computed heavy metal exposure routes for contaminated soils are made. The following exposure equations were used to compute ADI (mg/kg/day) for the various routes as directed by (U.S. Environmental Protection Agency, 1989).

2.6. Contact with the skin, ingestion, and inhalation of heavy metals

Equations (7) - (9) demonstrate the equation for estimating the average daily intake of heavy metals from food, inhalation, and skin contact with soil

$$ADI_{ing} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT} \quad (7)$$

$$ADI_{inh} = \frac{C_s \times IR_{air} \times EF \times ED}{BW \times AT \times PEF} \quad (8)$$

$$ADI_{dems} = \frac{C_s \times SA \times FE \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \quad (9)$$

where ADIing is the average daily intake of heavy metals ingested from soil in mg/kg$^{/day}$, C/CS is the concentration of heavy metal in mg/kg for soil. IR in mg/day is the ingestion rate, EF in days/year is the exposure frequency, ED is the exposure duration in years, BW is the body weight of the exposed individual in kg, AT is the time period over which the dose is averaged in days. CF is the conversion factor in kg/mg, C/CS is the content of heavy metal in mg/kg for soil, and ADIing is the average daily ingestion of heavy metals eaten from soil in mg/kg per day. The ingestion rate is expressed in mg/kg per day, the exposure frequency is expressed in days/year, the exposure length is expressed in years, the exposed person's body weight is expressed in kg, and the average exposure time is expressed in days. The conversion factor in kg/mg is CF. PEF is the particle emission factor, and ADIinh is the average daily intake of heavy metals breathed from soil in mg/kg per day. IRair is the inhalation rate in m^3/day. ADIdems stands for the exposure dosage via dermal contact in mg/kg per day, SA for the exposed skin area in cm^2, FE for the portion of the dermal exposure ratio to soil, AF for the portion of the applied dose absorbed across the skin, and ABS for the portion of the applied dose. Table 1 display the exposure parameters that were utilized in the HRA for several exposure paths in the typical home exposure scenario.

2.7. Analysis of the danger of non-carcinogens

The term 'hazard quotient' (HQ), which is a unitless quantity that reflects the likelihood that a person may have a negative outcome, is used to describe non-

Table 1. Exposure parameters applied to the evaluation of health risks associated with soil exposure via various exposure paths

S/N	Parameters	Unit	Child	Adult	References
1.	Body Weight (*BW*)	kg	15	70	DEA (2010)
2.	Exposure Factor (*EF*)	days/year	350	350	DEA (2010)
3.	Exposure Duration (*ED*)	year	6	30	DEA (2010)
4.	Ingestion Rate (*IR*)	mg/day	200	100	DEA (2010)
5.	Inhalation Rate (*IRair*)	m^3/day	10	20	DEA (2010)
6.	Skin Surface Area (*SA*)	cm^2	2100	5800	DEA (2010)
7.	Soil Adherence Factor (*AF*)	mg/cm^2	0.2	0.07	DEA (2010)
8.	Dermal Absorption Factor (*ABS*)	none	0.1	0.1	DEA (2010)
9.	Dermal Exposure Ratio (*FE*)	none	0.61	0.61	DEA (2010)
10.	Particulate Emission Factor (*PEF*)	m^3/kg	1.3×10^9	1.3×10^9	DEA (2010)
11.	Conversion Factor (*CF*)	kg/mg	10^{-6}	10^{-6}	DEA (2010)
12.	Average Time (*AT*) For-Carcinogens For Non-Carcinogens	days	365×70 365×ED	365×70 365×ED	DEA (2010) DEA (2010)

carcinogenic dangers. The following equation 10 (U.S. Environmental Protection Agency, 1989) is used to represent it:

$$HQ = \frac{ADI}{RfD} \quad (10)$$

The Hazard Index (HI), which is a total of all the HQs resulting from particular metals, is detailed by a USEPA document (U.S. Environmental Protection Agency, 1989). The mathematical representation of this parameter is seen in equation (11):

$$HI = \sum\nolimits_{k=1}^{n} HQ_k = \sum\nolimits_{k=1}^{n} \frac{ADI_k}{RfD_k} \quad (11)$$

where the values of heavy metal k are HQk, ADIk, and RfDk. The exposed population is unlikely to incur negative health impacts if the HI value is less than one, but if it surpasses one, there may be cause for worry about non-carcinogenic effects (U.S. Environmental Protection Agency, 1989).

2.8. Evaluation of the risk of cancer

For possible carcinogens, the risks are calculated as the lifetime cumulative likelihood of a person contracting cancer as a result of exposure to the potential carcinogen. The formula for estimating the increased lifetime cancer risk is given in equation 12 below:

$$Risk_{pathway} = \sum\nolimits_{k=1}^{n} ADI_k CSF_k \quad (12)$$

where Risk is the lifetime risk, expressed as a unitless probability, that a person would acquire cancer. The average daily intake (ADIk) and cancer slope factor (CSFk) for the kth heavy metal, respectively, are measured in milligrams per kilogram per day for an infinite number of metals. The slope factor directly translates the EDI of the heavy metal averaged over a lifetime of exposure to an individual's incremental cancer risk (U. S. Environmental Protection Agency, 1989). Equation 13 is used to compute the overall extra lifetime cancer risk for an individual based on the average contribution of each heavy metal for each route.

$$Risk_{(total)} = Risk_{(ing)} + Risk_{(inh)} + Risk_{(dermal)} \quad (13)$$

where the contributions to risk from ingestion, inhalation, and cutaneous channels are designated as Risk (ing), Risk(inh), and Risk(dermal). As indicated in Table 2, RfD and CSF values mostly obtained from the Department of Environmental Affairs (South Africa) and USEPA are used to determine both the non-carcinogenic and carcinogenic risk (CR) evaluation of heavy metals.

3. Results and discussions

In this study, attempts are made to unravel the effect of urbanization on the soil environment by analyzing data obtained from published research papers. To effectively achieve this, the following research questions were postulated: 1. Were the soil samples collected from major cities across the world? 2. Were the samples collected following international best techniques for sampling urban soils? 3. At what depths were the samples collected? 4. Were the samples well prepared in the laboratory prior to chemical analysis? 5. Do the analytical techniques employed meet the minimum requirements for geochemical analysis? 6. What are the concentrations of heavy metals in urban soils analyzed? 7. Are the concentrations of the metals in urban soils above the average crustal values? 8. Are these soils contaminated by the studied heavy metals? 9. To what extent are the soils contaminated by the metals? 10. What is the extent of environmental risks pose by the metals in the urban

Table 2. The various heavy metals' reference doses (RfD) in mg/kg per day and cancer slope factors (CSF)

S/N	Heavy Metal	Oral RfD	Dermal RfD	Inhalation RfD	Oral CSF	Dermal CSF	Inhalation CSF	References
1.	As	3.00E−4	3.00E−4	3.00E−4	1.50E + 0	1.50E + 0	1.50E + 1	DEA (2010)
2.	Pb	3.60E−3	-	-	8.50E−3	-	4.20E−2	DEA (2010)
3.	Hg	3.00E−4	3.00E−4	8.60E−5	-	-	-	DEA (2010)
4.	Cd	5.00E−4	5.00E−4	5.70E−5	-	-	6.30E + 0	DEA (2010)
5.	Cr(VI)	3.00E−3	-	3.00E−5	5.00E−1	-	4.10E + 1	DEA (2010)
6.	Co	2.00E−2	5.70E−6	5.70E−6	-	-	9.80E + 0	DEA (2010)
7.	Ni	2.00E−2	5.60E−3	-	-	-	-	DEA (2010)
8.	Cu	3.70E−2	2.40E−2	-	-	-	-	DEA (2010)
9	Zn	3.00E−1	7.50E−2	-	-	-	-	DEA (2010)
10.	Fe	7.00E−3						

soils? 11. Are the health of the inhabitants of these cities under any danger from metals in the soils? 12. What are the major sources of the metals in the global urban soils?

3.1. Collection, processing, and chemical analysis of the sample

Table 3 summarizes sample collection, preparation, and analytical techniques used by various studies carried out in different urban areas of the world evaluated in this study. A total of twenty-one thousand and nine hundred and thirty-two (21932) soil samples were collected from one hundred and seventy-seven cities across the world. The fewest samples (3 each) were collected from the cities of Krakow, Warszawa, Wroclaw, and Opole in Poland, while the highest number of samples were collected in Lianyuan City (6091) in China (Table 3). Soil samples were collected using random and systematic sampling techniques. Following the international acceptable techniques for geochemical mapping, the samples were collected at depths of 0–1 cm, 0–2 cm, 0–3 cm, 0–5 cm, 0–10 cm, 0–15 cm, 0–20 cm, and 0–100 cm, respectively (Table 3). Digestion of samples was done using one or a combination of the following chemical methods: aqua regia (HNO_3-HCl), HNO_3-HF-$HClO_4$, HNO_3-H_2O_2, HCl-HF-HNO_3-$HClO_4$, HF-HNO_3, and HNO_3 (Table 3). Analytical instruments (both singly or combined) used to analyze heavy metals in soils samples were Inductively Coupled Plasma-Mass Spectrometer (ICP-MS), Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES), Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES), Flame Atomic Absorption Spectrometer (FAAS), Atomic Absorption Spectrometer (AAS), X-ray fluorescence (XRF), Energy Dispersive X-ray Fluorescence (EDXRF), Hydride generation-atomic absorption spectroscopy (HG-AAS), Graphite furnace atomic absorption spectrometry (GFAAS), quadrupole inductively coupled plasma mass spectrometry (QICP-MS) and Laser Ablation-Inductively Coupled Plasm-Mass Spectrometry (LA-ICP-MS). In this study, 55%, 91%, 23%, 80%, 87%, 44%, 79%, 88%, 89%, and 37% of the studies reported values for As, Pb, Hg, Cd, Cr, Co, Ni, Cu, Zn, and Fe, respectively.

3.2. Heavy metal levels in urban soils across the world

The concentration of heavy metals in the soils of cities across different continents of the world together with their average crustal values are presented in Table 4. Among the cities, the concentration of metals in soils varied over a large range. In general, there were relatively high levels of heavy metals in soils of cities especially in developed countries. The range (mg/kg) of heavy metals in urban soils in Asia is: As (3.03–152), Pb (2.27–5780), Hg (0.05–178.19), Cd (0.10–163.90), Cr (1.10–900), Co (0.52–121.05), Ni (1.40–2560), Cu (2.30–12,986), Zn (1.14–3370), and Fe (34.39–88,531). According to this study, the concentrations of heavy metals in urban soils in Asia vary from 3.03 to 152 mg/kg for As, 2.27 to 5780 mg/kg for Pb, 0.10 to 178.19 mg/kg for Hg, 1.10 to 900 mg/kg for Cr, 0.52 to 121.05 mg/kg for Co, and 34.39 to 88,531 mg/kg for Fe. The range (mg/kg) of heavy metals in the soils of cities in Europe is: As (1.09–79.40), Pb (6.24–437), Hg (0.05–1.16), Cd (0.15–31.50), Cr (1.64–192.20), Co (5.90–22.62), Ni (2.89–120.12), Cu (7.66–1,270), Zn (6.35–3420), and Fe (358–56,350). In Africa, the range (mg/kg) of heavy metals in urban soils are: As (1.29–24.28), Pb (4.57–2418), Hg (0.07–38.4), Cd (0.03–298.90), Cr (4.74–264.80), Co (12.50–68.20), Ni (6.53–88.36), Cu (2.08–3277), Zn (12.50–3215.80) and Fe (119.89–119.89). In South America, the range (mg/kg) of heavy metals in urban soils is: As (1.47–51), Pb (5.71–135.30), Cd (0.10–0.45), Cr (0.04–3), Co (3.42–34.56), Ni (0.56–20.58), Cu (4.28–66), Zn (15.46–766.82), and Fe (28.10–56508). In North America, the range (mg/kg) of heavy metals in urban soils is: As (0.95–124.30), Pb (18.70–1420), Cd (0.40–4.50), Cr (9.55–1631.43), Co (0.41–14.00), Ni (2.28–445), Cu (7.75–94), Zn (37–663), and Fe (38571–52000). Overall, the range of heavy metals in the soils of cities across the world is: As

Table 3. Analysis of heavy metals in urban soils, sampling methods, and analytical procedures

S/N	City	Country	No of Samples	Depth of Sampling	Digestion/Analytical Procedure	As	Pb	Hg	Cd	Cr	Co	Ni	Cu	Zn	Fe	Source
1	Addis Ababa	Ethiopia	07	0-5 cm	HNO_3-HCl/ GC-MS		√		√			√	√	√		Prasse et al. (2012)
2	Ahvaz	Iran	92	0-20 cm	ICP-MS	√	√	√	√	√	√	√	√	√	√	Keshavarzi et al. (2019)
3	Akure	Nigeria	16	0-10 cm	Aqua Regia/AAS	√	√		√	√	√	√	√	√	√	Adewumi (2022)
4	Al Jubail	Saudi Arabia	116	0-15 cm	HNO_3-H_2O_2/ICP-AES		√		√	√	√	√	√	√		Alshahri (2019)
5	Aliaga	Turkey	40	0-5 cm	HNO_3-HCl/ ICP-MS	√	√	√	√	√	√	√	√	√	√	Kara et al. (2014)
6	Ancona	Italy	57	0-5 cm	Aqua Regia/ICP-MS		√	√		√	√	√	√	√		Serrani et al. (2022)
7	Anhui	China	24	0.20 cm	HNO_3-HCl/ICP-OES	√	√		√	√		√	√	√		Li et al. (2019)
8	Annaba	Morocco	101	0-20 cm	HNO_3/AAS, FAAS		√		√	√			√	√	√	Maas et al. (2010)
9	Anshan	China	115	0-10 cm	HNO_3-$HClO_4$-HF		√		√	√		√	√	√		Qing et al. (2015)
10	Arak	Iran	235	0-5 cm	HNO_3/FAAS, ICP-OES	√	√		√			√	√	√		Taati et al. (2020)
11	Aviles	Spain	17	0-25 cm	HCl-HNO_3-H_2O_2/ICP-MS	√	√	√	√	√	√	√	√	√	√	Ordóñez et al. (2015)
12	Babao	China	148	0-20 cm	HF-HCl-$HClO_4$ /ICP-MS	√	√	√	√	√	√	√	√	√		Tian et al. (2021)
13	Balkhash	Kazakhstan	90	0-20 cm	HF- HNO_3 /FAAS		√		√	√			√	√		Ramazanova et al. (2021)
14	Bangkok	Thailand	15	0-10 cm	HCl-HNO_3/FAAS		√		√			√	√	√	√	Damrongsiri et al. (2016)
15	Baoji	China	50	0-20 cm	XRF	√	√			√			√	√		Li et al. (2017)
16	Bar	Montenegro	15	0-10 cm	MAD/GFAAS,ICP-OES		√		√	√			√	√		Mugoša et al. (2016)
17	Beijing	China	80	0-20 cm	HF-HNO_3-$HClO_4$ /ICP-OES, ICP-MS	√	√		√	√		√	√	√		Chen et al. (2010)
18	Beishan	China	06	0-15 cm			√		√	√		√	√	√		Xun et al. (2018)
19	Belgrade	Serbia	15	0-10 cm	ICP-OES		√			√		√	√	√		Pavlović et al. (2018)
20	Berlin	Germany	30	0-1 cm	HNO_3-$HClO_4$-HF/ ICP-MS	√	√		√			√	√	√		Lottermoser et al. (2012)
21	Bijie	China	177		HCl-HNO_3-$HClO_4$-HF /XRF, ICP-MS		√			√	√	√	√	√		Yuan et al. (2017)
22	Bogota	Colombia	09	0-5 cm	ICP-MS/ICP-AES/HPLC	√	√	√	√	√	√	√	√	√	√	Donado et al. (2021)
23	Bogra	Bangladesh	48	0-20 cm	HCl-HNO_3/ICP-MS	√	√		√	√		√	√			Islam et al. (2015)
24	Bratislava	Slovakia	39	0-10 cm	$HClO_4$-HF/QICPMS	√	√			√	√	√	√	√	√	Hiller et al. (2021)
25	Brno	Czech	37	0-5 cm	Aqua Regia/ICP-MS	√	√		√	√		√	√	√		Pecina et al. (2021)
26	Budva	Montenegro	08	0-10 cm	MAD/GFAAS,ICP-OES		√		√	√			√	√		Mugoša et al. (2016)
27	Buenos Aires	Argentina	171	0-10 cm	ICP-MS, ICP-AES		√	√	√	√		√	√	√		Cittadino et al. (2020)
28	Cairo	Egypt	10	0-30 cm	XRF		√		√	√	√	√	√	√		Gomaa et al. (2020)
29	Cape Town	South Africa	34	0-10 cm	XRF	√	√							√	√	Shezi et al. (2022)
30	Centinje	Montenegro	04	0-10 cm	MAD/GFAAS,ICP-OES		√		√	√			√	√		Mugoša et al. (2016)
31	Changchun	China	61	0-5 cm	Aqua regia/ICP-MS	√	√		√	√	√	√	√	√		Peng et al. (2021)
32	Chongqing	China	1348	0-20 cm	HCl-$HClO_4$-HNO_3/ICPMS, AFS	√	√	√	√	√		√	√	√		Dong et al. (2018)
33	Colombo	Sri Lanka	90	0-5 cm	HNO_3-$HClO_4$-HF /AAS		√					√	√	√		Herath et al. (2018)
34	Concepcion	Chile	15	0-5 cm	Aqua Regia/ICP-MS	√	√		√	√		√	√	√	√	Rodríguez-Oroz et al. (2018)
35	Copiapo	Chile	42	0-15 cm	XRF	√	√			√			√	√	√	Carkovic et al. (2016)
36	Coronel	Chile	43	0-10 cm	Aqua Regia/ICP-AES		√			√	√	√	√	√		Tume et al. (2022)
37	Darkhan	Mongolia	126	0-10 cm	HCl-HF-HNO_3/ICP-MS, ICP-AES	√	√		√	√	√	√	√	√		Timofeev et al. (2019)
38	Daye	China	90	0-5 cm	HCl-HNO_3-HF /ICP-OES	√	√		√	√			√			Wang et al. (2021)
39	Delhi	India	22	0-15 cm	HNO_3-$HClO_4$/AAS		√			√			√	√		Bhatia et al. (2015)

(*Continued*)

Table 3. (Continued).

S/N	City	Country	No of Samples	Depth of Sampling	Digestion/Analytical Procedure	As	Pb	Hg	Cd	Cr	Co	Ni	Cu	Zn	Fe	Source
40	Detroit	USA	34	0-15 cm	XRF	√	√	√	√	√	√	√				Howard et al. (2019)
41	Dhaka	Bangladesh	70	0-10 cm	HCl-HNO_3/ICP-MS	√	√		√	√		√	√			Islam et al. (2020)
42	Dongguan	China	124	0-20 cm	ICP-MS		√		√	√			√	√		Tian et al. (2020)
43	Dublin	Ireland	1058	0-5 cm	ICP-AES	√	√	√	√	√	√	√	√	√		Glennon et al. (2014)
44	Durgapur Calcutta	India	54	0-15 cm	$HClO_4$-HNO_3/AAS		√		√	√		√	√		√	Pobi et al. (2020)
45	Estarreja	Portugal	26	0-20 cm	Aqua Regia/ICP-MS	√	√		√	√		√	√	√		Cachada et al. (2012)
46	Florida	USA	26	0-15 cm	HNO_3-H_2O_2/ICP-MS	√	√		√	√	√	√	√	√		da Silva et al. (2020)
47	Fuxin	China	306	0-20 cm	HNO_3-H_2O_2 /ICP-OES	√	√		√	√		√	√	√		Chen et al. (2015)
48	Ghaziabad	India	42	0-20 cm	HCl-HNO_3-H_2O_2 /FAAS		√		√			√	√	√	√	Chabukdhara and Nema (2013)
49	Ghent	Belgium	2169	0-30 cm	HNO_3-HCl-HF/ICPMS	√	√	√	√	√		√	√	√		Delbecque and Verdoodt (2016)
50	Guangzhou	China	402	0-20 cm	FAAS, GFAAS	√	√	√	√	√		√	√	√		Xiao et al. (2020)
51	Guiyang	China	50	0-5 cm	HNO_3-$HClO_4$/FAAS	√	√		√			√	√	√		Li et al. (2012)
52	Gujranwala	Pakistan	120	0-20 cm	HNO_3-HCl/AAS		√		√	√		√	√	√		Yousaf et al. (2016)
53	Haikou	China	70	0-20 cm	HF-HNO_3 /ICP-AES, ICP-MS	√	√		√	√		√	√	√	√	Bi et al. (2020)
54	Hamedan	Iran	34	0-10 cm	Aqua regia/ICP-MS	√	√	√	√	√	√	√	√	√		Modabberi et al. (2018)
55	Hangzhou	China	45	0-10 cm	HCl-HNO_3-$HClO_4$-HF /ICP-MS		√		√	√	√	√	√	√		Wang and Zhang (2018)
56	Harare	Zimbabwe	60	0-5 cm	HNO_3-HCl/AAS		√		√	√			√			Kanda et al. (2018)
57	Hassi Messoud	Algeria	58	0-20 cm	HNO_3-HCl/AAS		√					√	√	√		Benhaddya and Hadjel (2014)
58	Havana	Cuba	72	0-10 cm	XRF		√				√	√	√	√		Rizo et al. (2011)
59	Herceg Novi	Montenegro	09	0-10 cm	MAD/GFAAS,ICP-OES		√		√	√			√	√		Mugoša et al. (2016)
60	Ho Chi Minh	Vietman	09		INAA	√					√			√	√	Thien et al. (2021)
61	Hyderabad	India	16	10-50 cm	XRF		√			√	√	√	√	√		Machender et al. (2011)
62	Ibadan	Nigeria	43	0-15 cm	HNO_3-HCl/ ICP-MS	√	√		√	√	√	√	√	√	√	Kolawole et al. (2022)
63	Ijero-Ekiti	Nigeria	35	0-20 cm	Aqua Regia/ICP-MS	√	√	√	√	√	√	√	√	√	√	Laniyan and Adewumi (2020)
64	Islamabad	Pakistan	14	0-5 cm	FAAS	√	√		√	√	√	√	√	√	√	Iqbal et al. (2012)
65	Istanbul	Turkey	24	0-2 cm	HNO_3-HF/ ICP-MS		√			√		√	√	√		Guney et al. (2010)
66	Jiyuan	China	28	0-20 cm	HCl-HF-HNO_3-$HClO_4$/AAS	√	√	√	√	√		√	√	√	√	Wu et al. (2020)
67	Kaft El-Zayat	Egypt	16	0-25 cm	LA-ICP-MS		√		√	√			√			Shaheen et al. (2021)
68	Kajaran	Armenia	35	0-10 cm	EDXRF		√				√		√	√	√	Tepanosyan et al. (2018)
69	Kana Sura	Iran	08	0-15 cm	HF-HNO_3-$HClO_4$/ICP-MS	√	√		√	√	√	√	√	√	√	Hawrami et al. (2020)
70	Kani Kolka	Iran	13	0-15 cm	HF-HNO_3-$HClO_4$/ICP-MS	√	√		√	√	√	√	√	√	√	Hawrami et al. (2020)
71	Karachi	Pakistan	30	0-10 cm	$HClO_4$-HNO_3/FAAS		√			√			√	√	√	Karim and Qureshi (2014)
72	Kathmandu	Nepal	24	0-15 cm	HF-HNO_3-$HClO_4$ /ICP-AES	√	√		√	√	√	√	√	√	√	Yadav et al. (2019)
73	Kerman	Iran	38	0-5 cm	HNO_3-$HClO_4$-HF /ICP-MS		√		√	√			√	√	√	Hamzeh et al. (2011)
74	Kinshasa	DR Congo	15	0-5 cm	HNO_3-$HClO_4$-HF/ ICP-MS	√	√	√	√	√			√	√		Mavakala et al. (2022)
75	Konya	Turkey	17	0-20 cm	ICP-MS/ICP-OES	√	√	√	√	√	√	√	√	√	√	Ozlurk and Arici 2020
76	Kotor	Montenegro	07	0-10 cm	MAD/GFAAS,ICP-OES		√		√	√			√	√		Mugoša et al. (2016)
77	Kragujevac	Serbia	44	0-10 cm	HNO_3-H_2O_2/ICP-OES	√	√		√	√	√	√	√	√	√	Stajic et al. (2016)
78	Krakow	Poland	03	0-20 cm	Aqua regia/ICP-MS		√		√			√	√	√		Adamiec (2017)

(*Continued*)

Table 3. (Continued).

S/N	City	Country	No of Samples	Depth of Sampling	Digestion/Analytical Procedure	As	Pb	Hg	Cd	Cr	Co	Ni	Cu	Zn	Fe	Source
79	Kumasi	Ghana	20	0-10 cm	XRF		√			√	√		√	√		Acheampong et al. (2016)
80	Kumba	Cameroon	12	0-10 cm	HNO_3-HCl/ QICP-MS		√		√	√	√	√	√	√		Ngole-Jeme (2016)
81	Lagos	Nigeria	21	0-10 cm	HNO_3-HCl/ ICP-OES		√		√	√		√	√	√		Isimekhai et al. (2017)
82	Lahore	Pakistan	101	0-5 cm	HNO_3-$HClO_4$ /AAS		√		√	√		√				Alam et al. (2015)
83	Lanzhou	China	10	0-10 cm	HCl-HNO_3 /ICP-MS		√		√	√		√	√	√		Li et al. (2020)
84	Las Tunas	Cuba		0-10 cm	XRF		√			√	√	√	√	√	√	Díaz Rizo et al. (2013)
85	Lianyuan	China	6078		HNO_3-$HClO_4$-HF /ICP-MS, ICP-OES	√	√	√	√	√			√	√	√	Liang et al. (2017)
86	Lianyungang	China	16	0-10 cm	ICP-AES	√	√		√	√			√	√		Li et al. (2017)
87	Lin'an	China	62	0-20 cm	HF-HNO_3-$HClO_4$ /ICP-OES		√		√	√			√	√		Yu et al. (2019)
88	Longkou	China	138	0-20 cm	H_2SO_4-HNO_3-$HClO_4$-HF /FAAS	√	√	√	√	√		√	√	√		Jianfei et al. (2020)
89	Los Angeles	Chile	20	0-5 cm	Aqua Regia/ICP-MS	√	√		√	√		√	√	√	√	Rodríguez-Oroz et al. (2018)
90	Los Angeles	USA	74	0-15 cm	ICP-MS	√	√		√							Clarke et al. (2015)
91	Lublin	Poland	50	0-5 cm	EDXRF, AMA-254		√	√	√	√	√	√		√		Zgłobicki et al. (2021)
92	Mahad Ad'Dahab	Saudi Arabia	05	0-3 cm	HNO_3/ICP-OES		√		√	√	√	√		√	√	Al-Swadi et al. (2022)
93	Riyadh	Saudi Arabia	05	0-3 cm	HNO_3/ICP-OES		√		√	√	√	√		√	√	Al-Swadi et al. (2022)
94	Manaus	Brazil	22	0-20 cm	HNO_3-HCl/ICP-OES		√		√	√	√	√	√	√	√	Ferreira et al. (2021)
95	Melbourne	Australia														Kandic et al. (2019)
96	Mianyang	China	101	0-20 cm	XRF	√	√			√	√	√	√	√		Du and Lu (2022)
97	Moa	Cuba	28	0-10 cm	XRF					√	√	√			√	Diaz-Rizo et al. (2011)
98	Mojo	Ethiopia		0-20 cm	HNO_3-HCl/ ICP-OES	√	√	√	√	√	√	√	√	√	√	Gebeyehu et al. (2020)
99	Moscow	Russia	52	0-10 cm	ICP-MS, ICP-AES	√	√		√	√	√	√	√	√		Kosheleva et al. (2018)
100	Mumbai	India	18 (for 2 years)	0-100 cm	HF-HCl-$HClO_4$-HNO_3/ICP-MS, ICP-AES					√	√	√	√	√		Vazhacharickal et al. (2019)
101	Murcia	Spain	221	0-5 cm	HNO_3-$HClO_4$/ICP-MS		√		√	√		√	√	√		Acosta et al. (2010)
102	Nanjing	China	50	0-20 cm	HNO_3-$HClO_4$-HF /ICP-MS		√		√	√		√	√	√		Li et al. (2022)
103	New York City	USA	141	0-5 cm	ICP-MS		√	√	√	√	√	√	√	√		Burt et al. (2014)
104	Ningbo	China	665	0-20 cm	HCl-HF-HNO_3-$HClO_4$/ICP-MS, ICP-OES	√	√	√	√	√		√	√	√		Xiang et al. (2020)
105	Novi Sad	Serbia	21	0-10 cm	HNO_3-H_2O_2/AAS		√		√	√		√	√	√	√	Škrbić and Đurišić-Mladenović (2013)
106	Obrenovac	Serbia	08	0-20 cm	ICP-OES		√			√	√	√	√	√	√	Pavlović et al. (2021)
107	Obuasi	Ghana	20	0-20 cm	HNO_3-HCl/ ICP-MS	√	√	√	√	√		√	√	√	√	Bempah and Ewusi (2016)
108	Ocala	USA	24	0-15 cm	HNO_3-H_2O_2/ICP-MS	√	√		√	√	√	√	√	√		da Silva et al. (2020)
109	Opole	Poland	03	0-20 cm	Aqua regia/ICP-MS		√		√			√	√	√		Adamiec (2017)
110	Orlando	USA	50	0-15 cm	HNO_3-H_2O_2/ICP-MS	√	√		√	√	√	√	√	√		da Silva et al. (2020)
111	Pancevo	Serbia	08	0-20 cm	ICP-OES		√			√	√	√	√	√	√	Pavlović et al. (2021)
112	Panzhihua	China	30	0-10 cm	HNO_3-$HClO_4$-HF/ICP-MS, ICP-AES		√		√	√		√	√	√		Long et al. (2021)
113	Paris	France	30	0-10 cm	Aqua Regia/HG-AAS, ICP-OES	√	√		√	√		√	√	√		Foti et al. (2017)
114	Pensacola	USA	24	0-15 cm	HNO_3-H_2O_2/ICP-MS	√	√		√	√	√	√	√	√		da Silva et al. (2020)
115	Philadelphia	USA	20	0-5 cm	ICP-OES		√			√			√	√		O'shea et al. (2021)
116	Pisa	Italy	100	0-20 cm	HNO_3-$HClO_4$/AAS	√	√	√	√	√		√	√	√		Bretzel and Calderisi (2011)
117	Port-Harcourt	Nigeria	21	0-15 cm			√	√	√				√	√		Olatunde and Onisoya (2017)

(*Continued*)

Table 3. (Continued).

S/N	City	Country	No of Samples	Depth of Sampling	Digestion/Analytical Procedure	As	Pb	Hg	Cd	Cr	Co	Ni	Cu	Zn	Fe	Source
118	Pristina	Kosovo	27	0-5 cm	ICP-OES	√	√		√	√	√	√	√			Gulan et al. (2017)
119	Quito	Ecuador	300	0-10 cm	HNO_3-H_2O_2/ICP-OES	√	√		√	√	√	√	√	√	√	Bonilla-Bedoya et al. (2021)
120	Ras Tanura	Saudi Arabia	34	0-20 cm	HCl-HNO_3-H_2O_2		√		√	√	√	√		√		Alshahri and El-Taher (2018)
121	Rawalpindi	Pakistan	24	0-20 cm	HNO_3-$HClO_4$ /AAS		√		√	√	√	√	√	√		Iqbal et al. (2012)
122	Ridder	Kazakhstan	90	0-20 cm	HF- HNO_3 /FAAS		√		√	√			√	√		Ramazanova et al. (2021)
123	Rio De Janeiro	Brazil	65	0-5 cm	FAAS				√	√			√	√		Parente et al. (2019)
124	Rome	Italy	10	0-20 cm	HCl-HNO_3-H_2O_2-HF/ICP-OES,ICP-MS		√		√				√	√		Montereali et al. (2017)
125	Sadat	Egypt	06		HPLC-ICPMS		√		√	√	√	√	√	√	√	Azzazy and Bhat (2020)
126	Sagamu	Nigeria	38	0-15 cm	HNO_3-$HClO_4$/FAAS		√		√	√			√	√		Ogunkunle and Fatoba (2014)
127	Salzburg	Austria	05	0-20 cm	ICP-OES	√	√			√		√	√	√		Pavlović et al. (2021)
128	San Luis Potosi	Mexico	26	0-5 cm	HNO_3/FAAS	√	√	√	√							Perez-Vazquez et al. (2015)
129	Sao Paulo	Brazil	200	0-20 cm	HCl-HNO_3/ICP-OES		√		√			√	√	√		dos Santos-Araujo and Alleoni (2016)
130	Sarajevo	Bosnia & Herzegovina	10	0-10 cm	ICP-OES	√	√	√	√	√	√	√	√	√	√	Sapcanin et al. (2017)
131	Segzed	Hungary	102	0-10 cm	Aqua Regia/ICP-OES	√	√		√	√	√	√	√	√		Szolnoki et al. (2013)
132	Shanghai	China	86	0-20 cm	HF-HNO_3-$HClO_4$ /AAS	√	√	√	√				√			Bi et al. (2018)
133	Shaoxing	China	60	0-20 cm	HNO_3-$HClO_4$ /XRF, ICP-MS	√	√	√	√	√		√	√	√	√	Chai et al. (2019)
134	Shenzhen	China	82	0-20 cm	HF-$HClO_4$-HNO_3, HNO_3-H_2O_2 /FAAS, GFAAS, ICP-MS		√		√	√			√	√		Wu et al. (2016)
135	Shymkent	Kazakhstan	90	0-20 cm	HF- HNO_3 /FAAS		√		√	√			√	√		Ramazanova et al. (2021)
136	Sialkot	Pakistan	82	0-15 cm	HNO_3-$HClO_4$-HCl /FS-AA,AFS		√		√	√	√	√	√	√	√	Malik et al. (2010)
137	Smedarevo	Serbia	08	0-20 cm	ICP-OES		√			√	√	√	√	√	√	Pavlović et al. (2021)
138	Suzhou	China	167	0-15 cm	HNO_3-$HClO_4$-HF /ICP-AES	√	√	√	√	√						Wang et al. (2017)
139	Sydney	Australia														Birch et al. (2011)
140	Taiyuan	China	80	0-20 cm		√	√	√	√	√		√	√	√		Liu et al. (2014)
141	Talcahuano	Chile	12	0-5 cm	Aqua Regia/ICP-MS	√	√		√	√		√	√	√		Rodríguez-Oroz et al. (2018)
142	Taldykorgan	Kazakhstan	90	0-20 cm	HF- HNO_3 /FAAS		√		√	√			√	√		Ramazanova et al. (2021)
143	Taltal	Chile	125	0-20 cm	Aqua Regia/ICP-OES	√	√		√	√	√	√	√	√	√	Reyes et al. (2020)
144	Tampa	USA	64	0-15 cm	HNO_3-H_2O_2/ICP-MS	√	√		√	√	√	√	√	√		da Silva et al. (2020)
145	Tehran	Iran	27	0-10 cm	HCl-HNO_3-H_2O_2 /AAS		√			√	√	√		√		Saeedi et al. (2012)
146	Thessaloniki	Greece	05	0-20 cm	ICP-OES	√	√			√		√	√	√		Pavlović et al. (2021)
147	Tianjin	China	31	0-5 cm	H_2SO_4-$HClO_4$-HNO_3/ICP-AES		√		√	√		√	√	√		Zeng et al. (2015)
148	Tivat	Montenegro	07	0-10 cm	MAD/GFAAS,ICP-OES		√		√	√			√	√		Mugoša et al. (2016)
149	Tome	Chile	10	0-5 cm	Aqua Regia/ICP-MS	√	√		√	√		√	√	√	√	Rodríguez-Oroz et al. (2018)
150	Torun	Poland	42	0-25 cm	HCl-HNO_3 /ICP-MS		√	√		√	√	√	√	√	√	Charzyński et al. (2017)
151	Toshki	Egypt	30	0-5 cm	NAA	√				√	√			√	√	El-Taher and Abdelhalim (2014)
152	Tshwane	South Africa	04	0-5 cm	HNO_3-$HClO_4$/ICP-MS		√		√	√		√	√	√	√	Lion and Olowoyo (2013)
153	Tyumen	Russia	241	0-10 cm	XRF	√	√			√	√	√	√	√	√	Konstantinova et al. (2019)
154	Ulaanbaatar	Mongolia	22	0-10 cm	HCl-HF-HNO_3-$HClO_4$/ICP-MS, ICP-OES	√	√		√	√	√	√	√	√	√	Bilguun et al. (2020)
155	Ulcinj	Montenegro	04	0-10 cm	MAD/GFAAS,ICP-OES		√		√	√			√	√		Mugoša et al. (2016)
156	Uslan	South Korea	14	0-20 cm	HNO_3-HCl/ICP-AES	√	√		√				√	√		Kim et al. (2020)

(*Continued*)

Table 3. (Continued).

S/N	City	Country	No of Samples	Depth of Sampling	Digestion/Analytical Procedure	As	Pb	Hg	Cd	Cr	Co	Ni	Cu	Zn	Fe	Source
157	Ust-Kamenogorsk	Kazakhstan	90	0-20 cm	HF- HNO_3 /FAAS		√		√	√			√	√		Ramazanova et al. (2021)
158	Veles	Macedonia	201	0-5 cm	HNO_3-HCl/ AAS	√	√	√	√	√	√	√	√	√	√	Stafilov et al. (2010)
159	Volos	Greece	27	0-10 cm	ICP-OES/ICP-MS	√	√		√	√		√	√	√	√	Kelepertzis et al. (2021)
160	Warszawa	Poland	03	0-20 cm	Aqua regia/ICP-MS		√		√			√	√	√		Adamiec (2017)
161	West Patin Beach	USA	26	0-15 cm	HNO_3-H_2O_2/ICP-MS	√	√		√	√	√	√	√	√		da Silva et al. (2020)
162	Wien	Austria	96	0–20	HNO_3-H_2O_2/ICP-OES	√	√		√	√	√		√	√		Simon et al. (2013)
163	Wroclaw	Poland	03	0-20 cm	Aqua regia/ICP-MS		√		√			√	√	√		Adamiec (2017)
164	Wuhan	China	477	0-20 cm	HNO_3-$HClO_4$ /ICP-MS		√	√	√	√	√	√	√	√		Filippelli and Laidlaw (2010)
165	Xi'an	China	62	0-10 cm	XRF	√	√		√	√	√	√	√	√		Zhang et al. (2019)
166	Xiamen	China	146	0-20 cm	HNO_3-HF-$HClO_4$/FAAS	√	√			√		√	√	√		Huang et al. (2019)
167	Xiangtan	China	63	0-20 cm	HNO_3 /ICP-AES		√		√	√	√	√	√			Deng et al. (2019)
168	Yaoundé	Cameroon	45	0-20 cm	HNO_3-HCl/ ICP-OES		√		√	√			√	√	√	Aboubakar et al. (2021)
169	Yazd	Iran	30	0-10 cm	HNO_3-$HClO_4$-HF-HCl /ICP-MS	√	√		√	√	√	√	√	√	√	Somajeh et al. (2021)
170	Yulin	China	24	0-20 cm	XRF	√	√			√	√	√	√	√	√	He et al. (2020)
171	Zagreb	Croatia	28	0-5 cm	Aqua Regia/ICP-OES	√	√		√	√	√	√	√	√	√	Roje et al. (2018)
172	Zakamensk	Russia	130	0-10 cm	ICP-MS, ICP-AES	√	√		√	√	√	√	√	√	√	Timofeev et al. (2018)
173	Zhangzhou	China	179	0-20 cm	FAAS/AFS	√	√	√		√		√	√	√		Huang et al. (2021)
174	Zunyi	China	256	0-5 cm	HF-HNO_3-$HClO_4$ /FAAS, ICP-MS	√	√	√	√	√		√	√	√		Wu et al. (2020)

Table 4. The distribution of heavy metals in urban soils across the world's continents

Continent	Statistics	As (mg/kg)	Pb (mg/kg)	Hg (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Co (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Fe (mg/kg)
Asia	Minimum	3.03	2.27	0.05	0.10	1.10	0.52	1.40	2.30	1.14	34.39
	Maximum	152.00	5780.00	178.19	163.90	900.00	121.05	2560.00	12986.00	3370.00	88531.00
	Average	20.11	**283.63**	**10.54**	**11.24**	**107.75**	**28.02**	**95.06**	**253.89**	**248.99**	27130.28
	% CV	148.14	298.53	378.37	243.57	117.11	94.04	331.44	574.84	176.88	82.79
Europe	Minimum	1.09	6.24	0.05	0.15	1.64	5.90	2.89	7.66	6.35	358
	Maximum	79.40	437.00	1.16	31.50	192.20	22.62	120.12	1270.00	3420.00	56350.00
	Average	**12.91**	**87.59**	**0.37**	**2.36**	48.20	11.39	41.12	**76.29**	**259.97**	22644.28
	% CV	118.53	113.88	89.77	228.74	87.38	42.49	73.28	238.38	226.47	67.18
Africa	Minimum	1.29	4.57	0.07	0.03	4.74	1.25	6.53	2.08	12.50	119.89
	Maximum	24.28	2418.00	38.40	298.90	264.80	68.20	88.36	3277.00	3125.80	74510.00
	Average	**7.71**	**228.47**	**11.58**	**22.66**	74.48	**23.03**	32.47	**247.22**	**415.12**	30970.31
	% CV	107.15	228.28	156.55	326.83	98.07	83.91	68.43	291.26	194.60	78.87
Australia	Minimum	-	102.00	-	-	17.00	-	13.00	40.00	187.00	-
	Maximum	8.00	194.00	-	0.40	19.00	6.00	15.00	46.00	218.00	17350.00
	Average	**8.00**	**148.00**	-	**0.40**	18.00	6.00	14.00	**43.00**	**202.50**	17350.00
	% CV	-	43.96	-	-	7.86	-	10.00	9.86	-	-
South America	Minimum	1.47	5.71	0.10	0.04	3.42	0.56	4.28	15.46	35.07	28.10
	Maximum	51.00	135.30	0.45	3.00	34.56	20.58	66.00	766.82	240.00	56508.00
	Average	**25.54**	**19.93**	**0.22**	**0.97**	19.38	10.04	20.54	**109.69**	**121.15**	28742.68
	% CV	54.15	230.79	89.99	108.96	47.59	75.71	85.12	181.72	259.33	90.39
North America	Minimum	0.95	18.70	0.40	0.16	9.55	0.41	2.28	7.75	37.00	38571.00
	Maximum	124.30	1420.00	16.50	4.50	1631.43	14.00	445.00	94.00	663.00	52000.00
	Average	**17.99**	**308.09**	**8.45**	**0.95**	**205.45**	4.67	**75.18**	**39.58**	**143.87**	45285.50
	% CV	239.28	149.96	134.73	155.52	232.36	127.28	192.15	91.51	139.04	20.96
Overall	Minimum	0.95	2.27	0.05	0.03	1.10	0.41	1.40	2.08	1.14	28.10
	Maximum	152.00	5780.00	178.19	298.90	1631.43	121.05	2560.00	12986.00	3420.00	88531.00
	Average	**17.36**	**206.97**	**6.81**	**8.68**	87.67	**18.59**	**65.58**	**179.35**	**256.26**	27401.01
	% CV	146.57	301.31	417.59	362.88	180.45	108.91	334.79	574.34	201.21	77.38
Average Crustal Value (ACV)		4.80	17.00	0.05	0.09	92.00	17.30	47.00	28.00	67.00	50400.00

(0.95–152), Pb (2.27–5780), Hg (0.05–178.19), Cd (0.03–289.90), Cr (1.10–1631), Co (0.41–121.05), Ni (1.40–2560), Cu (2.08–12986), Zn (1.14–3420), and Fe (28.10–88531). The results showed that the average amounts of As, Pb, Hg, Cd, Co, Ni, Cu, and Zn were above the average crustal values (ACV). The findings showed that As concentrations were above the ACV in 80% of urban soils and above the ACV for Pb concentrations in 92% of the soils. Additionally, Cd was above the ACV in 96% of the samples, whereas Hg was in 95% of the urban soil samples. Additionally, the concentrations of Cr, Co, Ni, and Fe were greater than the ACV in 26%, 36%, 30%, and 16% of urban soils, respectively, while the concentrations of Cu and Zn were higher in 71% and 75% of the soils. This indicated that these heavy metals are present in the majority of urban soils.

3.3. Arsenic levels in urban soils across the world

The amount of As in Asian urban soils is between 3.03 mg/kg and 152 mg/kg, while in European urban soils, its concentration is between 1.09 mg/kg and 79.40 mg/kg. Its concentration in African urban soils is between 1.29 mg/kg and 24.28 mg/kg, while in South American urban soils, its amounts are between 1.47 mg/kg and 51 mg/kg. In North American cities, the amount of As in urban soils is between 0.95 mg/kg and 124.30 mg/kg, while in Australia it is between 0 and 8 mg/kg. Overall, the range of As in soils of cities across the world are between 0.95 mg/kg and 152 mg/kg. The results showed that the average amounts of As were above their average crustal values (ACV) in 80% of the studied urban soils. The average distribution of As in cities across all the continents of the world is in the following order: South America > Asia > North America > Europe > Australia > Africa (Table 4). In Asia, the lowest concentration of As was observed in the city of Haikou, China (Bi et al., 2020), while the highest amount was found in Arak, Iran (Taati et al., 2020). In South America, the lowest amount of As was recorded in Quito, Ecuador (Bonilla-Bedoya et al., 2021), while the highest concentration was found in San Luis, Mexico. In North America, the lowest concentration of As was found in the soils of Orlando, USA (da Silva et al., 2020), while the lowest amount was observed in the soils of Detroit, USA (Howard et al., 2019). In Europe, the lowest value of As was recorded in the soils of Ghent, Belgium (Delbecque & Verdoodt, 2016), while the highest value was recorded in the soils of Pristina, Kosovo (Gulan et al., 2017). In Africa, the lowest concentration of As is found in the soils of Kinshasa (Mavakala et al., 2022), while the highest amount is found in the soils of Mojo, Egypt (Gebeyehu et al., 2020).

3.4. Lead levels in urban soils across the world

The amount of Pb in Asian urban soils is between 2.27 mg/kg and 5780 mg/kg, while in European urban soils, its concentration is between 6.24 mg/kg and 437 mg/kg. Its concentration in African urban soils is between 4.57 mg/kg and 2418 mg/kg, while in South American urban soils, its amounts are between 5.71 mg/kg and 135.30 mg/kg. In North American cities, the amount of Pb in soils is between 18.70 mg/kg and 1420 mg/kg, while in Australia it is between 102 mg/kg and 194 mg/kg. Overall, the range of Pb in the soils of cities across the world is between 2.27 mg/kg and 5780 mg/kg. The results showed that the average amounts of Pb were above their average crustal values (ACV) in 92% of the studied urban soils. The mean distribution of Pb in cities across all the continents of the world is in the following order: North America > Asia > Africa > Australia > Europe > South America (Table 4). The lowest concentration of Pb was recorded in the soils of Ras Tanura, Saudi Arabia (Alshahri & El-Taher, 2018), while its highest concentration is found in the soils of Kerman, Iran (Hamzeh et al., 2011). In Asia, the lowest amount of Pb is found in the soils of Ras Tanura, Saudi Arabia (Alshahri & El-Taher, 2018), while the highest concentration is found in the soils of Kerman, Iran (Hamzeh et al., 2011). In South America, the lowest Pb concentration was found in the soils of Rio de Janeiro, Brazil (Parente et al., 2019), while the highest concentration was found in the soils of Taltal, Chile (Reyes et al., 2020). In North America, the least amount of Pb was observed in the soils of Orlando, USA (da Silva et al., 2020), while the highest amount was found in the soils of Detroit (Howard et al., 2019). In Europe, the lowest amount of Pb was found in the soils of Ghent, Belgium (Delbecque & Verdoodt, 2016), while the highest concentration was found in the soils of Aliaga, Turkey (Kara et al., 2014). In Australia, the lowest concentration was found in soils in Melbourne (Kandic et al., 2019), while the highest amount was found in soils in Sydney (Birch et al., 2011). In Africa, the lowest amount of Pb was found in the soils of Sadat, Egypt (Azzazy & Bhat, 2020), while the highest concentration was found in the soils of Lagos, Nigeria (Isimekhai et al., 2017).

3.5. Mercury levels in urban soils across the world

The amount of Hg in Asian urban soils is between 0.05 mg/kg and 178.19 mg/kg, while in European urban soils, its concentration is between 0.05 mg/kg and 1.16 mg/kg. Its concentration in African urban soils is between 0.07 mg/kg and 38.40 mg/kg, while in South American urban soils, its amounts are between 5.71 mg/kg and 135.30 mg/kg. Overall, the range of Hg in the soils of cities across the world is between 0.05 mg/kg and 178.19 mg/kg. The results showed that the average amounts of Hg were above their average crustal values (ACV) in 95% of the studied urban soils. The average distribution of Hg in the soils of cities across continents of the world is in the following order: Africa > Asia > North America > Europe > South America (Table 4). Across the world, the least concentration of Hg was found in the soils of Longkou, China (Jianfei et al., 2020), while the highest amount was found in the soils of Lianyuan, China (Liang et al., 2017). In Europe, the least amount of Hg was found in the soils of Lublin, Poland (Zgłobicki et al., 2021), while the highest concentration was found in the soils of Ghent, Belgium (Delbecque & Verdoodt, 2016). In Africa, the lowest concentration of Hg was recorded in the soils of Ijero-Ekiti, Nigeria (Laniyan & Adewumi, 2020), while the highest concentration was recorded in the soils of Port-Harcourt, Nigeria (Olatunde & Onisoya, 2017). In South America, the lowest amount of Hg was found in the soils of Buenos Aires, Argentina (Cittadino et al., 2020), while the highest concentration was found in San Luis, Mexico (Perez-Vazquez et al., 2015).

3.6. Cadmium levels in urban soils across the world

The amount of Cd in Asian urban soils is between 0.10 mg/kg and 163.90 mg/kg, while in European urban soils, its concentration is between 0.15 mg/kg and 31.50 mg/kg. Its concentration in African urban soils is between 0.03 mg/kg and 298.90 mg/kg, while in South American urban soils, its amounts are between 0.10 mg/kg and 0.45 mg/kg. In North American cities, the amount of Cd in soils is between 0.40 mg/kg and 4.50 mg/kg, while in Australia it is between 0 and 0.40 mg/kg. Overall, the range of Pb in the soils of cities across the world is between 0.03 mg/kg and 289.90 mg/kg. The results showed that the average amounts of Cd were above their average crustal values (ACV) in 96% of the studied urban soils. The average distribution of Cd in cities across continents of the world is in the following order: Africa > Asia > Europe > South America > North America > Australia (Table 4). Across the world, the lowest concentration of Cd in urban soils was observed in Tshwane, South Africa (Lion & Olowoyo, 2013), while the highest amount was reported in the soils of Sagamu, Nigeria (Ogunkunle & Fatoba, 2014). In Asia, the lowest amount of Cd was found in the soils of Riyadh, Saudi Arabia (Al-Swadi et al., 2022), while the highest amount was found in the soils of Rawalpindi, Pakistan (Iqbal et al., 2012). In Europe, the lowest concentration of Cd was found in the soils of Konya, Turkey (Ozlurk & Arici, 2021) and Torun, Poland (Charzyński et al., 2017), while the highest concentration was found in the soils of Berlin, Germany (Lottermoser, 2012). In South America, the lowest amount of Cd was found in the soils of Rio de Janeiro (Parente et al., 2019), while the highest was found in the soils of San Luis, Mexico (Perez-Vazquez et al., 2015). In North America, the highest amount was found in the soils of Orlando, USA (da Silva et al., 2020), while the lowest amount was found in the soils of Detroit (Howard et al., 2019).

3.7. Chromium levels in urban soils across the world

The amount of Cr in Asian urban soils is between 1.10 mg/kg and 900 mg/kg, while in European urban soils, its concentration is between 1.64 mg/kg and 192.20 mg/kg. Its concentration in African urban soils is between 4.74 mg/kg and 264.80 mg/kg, while in South American urban soils, its amounts are between 0.04 mg/kg and 3.00 mg/kg. In North American cities, the amount of Cr in soils is between 9.55 mg/kg and 1631.43 mg/kg, while in Australia it is between 17 mg/kg and 19 mg/kg. Overall, the range of Cr in the soils of cities across the world is between 0.04 mg/kg and 289.90 mg/kg. The results showed that the average amounts of Cr were above their average crustal values (ACV) in 26% of the studied urban soils. The average distribution of Cr in soils of cities across continents of the world is in the following order: North America > Asia > Africa > Europe > South America > Australia (Table 4). Overall, the lowest amount of Cr is found in the soils of Taldykorgan, Kazakhstan (Ramazanova et al., 2021), while the highest amount is found in the soils of Moa, Cuba (Diaz-Rizo et al., 2011). In Asia, the lowest amount of Cr is found in the soils of Taldykorgan, Kazakhstan (Ramazanova et al., 2021), while the highest concentration is found in the soils of Beishan, China (Xun et al., 2018). In Europe, the lowest concentration of Cr was found in the soils of Ghent, Belgium

(Delbecque & Verdoodt, 2016), while the highest value was recorded in the soils of Lublin, Poland (Zgłobicki et al., 2021). In Africa, the lowest amounts of Cr were found in the soils of Ijero-Ekiti, Nigeria (Laniyan & Adewumi, 2020), while the highest concentrations were obtained in the soils of Kumasi, Ghana (Acheampong et al., 2016). In Australia, the lowest amounts of Cr were found in the soils of Sydney (Birch et al., 2011), while the highest were found in Melbourne (Kandic et al., 2019). In South America, the lowest concentrations of Cr were found in the soils of Rio de Janeiro, Brazil (Parente et al., 2019), while the highest amounts were recorded in the soils of Manaus, Brazil (Ferreira et al., 2021). In North America, the lowest amounts of Cr were found in the soils of Los Angeles, USA (Rodriguez-Oroz et al., 2018), while the highest concentrations were found in the soils of Moa, Cuba (Gebeyehu et al., 2020).

3.8. Cobalt levels in urban soils across the world

The amount of Co in Asian urban soils is between 0.52 mg/kg and 121.05 mg/kg, while in European urban soils, its concentration is between 5.90 mg/kg and 22.62 mg/kg. Its concentration in African urban soils is between 12.50 mg/kg and 68.20 mg/kg, while in South American urban soils, its amounts are between 3.42 mg/kg and 34.56 mg/kg. In North American cities, the amount of Co in soils is between 0.41 mg/kg and 14.00 mg/kg, while in Australia it is between 0 and 6 mg/kg. Overall, the range of Co in the soils of cities across the world is between 0.41 mg/kg and 121.05 mg/kg. The results showed that the average amounts of CO were above their average crustal values (ACV) in 36% of the studied urban soils. The mean amounts of CO in urban soils across continents of the world are in the following order: Asia > Africa > Europe > South America > Australia > North America (Table 4). Across the world, the lowest concentrations of CO were found in the soils of Orlando, USA (da Silva et al., 2020), while the highest concentrations were recorded in the soils of Al-Jubail, Saudi Arabia (Alshahri, 2019). In Asia, the lowest and highest concentrations of Co were observed in the soils of Ras Tanura (Alshahri & El-Taher, 2018) and Al-Jubail, Saudi Arabia (Alshahri, 2019), respectively, while in Europe, the lowest and highest amounts of Co were recorded in the soils of Bratislava, Slovakia (Hiller et al., 2021) and Berlin, Germany (Lottermoser, 2012). In Africa, the lowest and highest values of Co were obtained in the soils of Sadat, Egypt (Azzazy & Bhat, 2020) and Kumasi, Ghana (Acheampong et al., 2016), while in South America, the lowest and highest amounts were recorded in the soils of Manaus, Brazil (Ferreira et al., 2021) and Taltal, Chile (Reyes et al., 2020). In North America, the lowest and highest concentrations of CO were found in the soils of Orlando, USA (da Silva et al., 2020) and Las Tunas, Cuba (Díaz Rizo et al., 2013).

3.9. Nickel levels in urban soils across the world

The amount of Ni in Asian urban soils is between 1.40 mg/kg and 2560 mg/kg, while in European urban soils, its concentration is between 2.89 mg/kg and 120.12 mg/kg. Its concentration in African urban soils is between 6.53 mg/kg and 88.36 mg/kg, while in South American urban soils, its amounts are between 0.56 mg/kg and 20.58 mg/kg. In North American cities, the amount of Ni in soils is between 2.28 mg/kg and 445 mg/kg, while in Australia it is between 13 mg/kg and 15 mg/kg. Overall, the range of Ni in the soils of cities across the world is between 1.40 mg/kg and 2560 mg/kg. The results showed that the average amounts of Ni were above their average crustal values (ACV) in 30% of the studied urban soils. The average distribution of Ni in urban soils across the continents of the world is in the following order: Asia > North America > Europe > Africa > South America > Australia (Table 4). The lowest and highest amounts of Ni in urban soils across the world were found in the soils of Mumbai, India (Vazhacharickal et al., 2019), and Beishan, China (Xun et al., 2018). In Europe, the lowest and highest amounts of Ni in urban soils were found in Ghent, Belgium (Delbecque & Verdoodt, 2016) and Kragujevac, Serbia (Stajic et al., 2016), respectively, while in Africa, the lowest and highest amounts were found in the soils of Ijero-Ekiti, Nigeria (Laniyan & Adewumi, 2020) and Kaft El-Zayat, Egypt (Shaheen et al., 2021). In Australia, the lowest and highest amounts of Ni were found in the soils of Melbourne (Kandic et al., 2019) and Sydney (Birch et al., 2011), respectively. In South America, the lowest and highest values of Ni were observed in the soils of Manuas, Brazil (Ferreira et al., 2021) and Taltal, Chile (Reyes et al., 2020), while in North America, the lowest and highest values were obtained in the soils of Orlando (da Silva et al., 2020) and Moa, USA (Diaz-Rizo et al., 2011), respectively.

3.10. Copper levels in urban soils across the world

The amount of Cu in Asian urban soils is between 2.30 mg/kg and 12,986 mg/kg, while in European urban soils, its concentration is between 7.66 mg/kg and 1,270 mg/

kg. Its concentration in African urban soils is between 2.08 mg/kg and 3277 mg/kg, while in South American urban soils, its amounts are between 4.28 mg/kg and 66 mg/kg. In North American cities, the amount of Cu in soils is between 7.75 mg/kg and 94 mg/kg, while in Australia it is between 40 mg/kg and 46 mg/kg. Overall, the range of Ni in the soils of cities across the world is between 2.08 mg/kg and 12,986 mg/kg. The results showed that the average amounts of Ni were above their average crustal values (ACV) in 71% of the studied urban soils. The average distribution of Cu in urban soils across the continents of the world is in the following order: Asia > Africa > South America > Europe > Australia > North America (Table 4). According to this study, Sadat, Egypt (Azzazy & Bhat, 2020) and Bangkok, Thailand (Damrongsiri et al., 2016) have the lowest and highest quantities of copper in soils worldwide, respectively. In Asia, the lowest and highest values of Cu were recorded in the soils of Taldykongman, Kazakhstan (Ramazanova et al., 2021) and Bangkok, Thailand (Damrongsiri et al., 2016), while in Europe, the lowest and highest amounts of Cu were found in the soils of Ghent, Belgium (Delbecque & Verdoodt, 2016) and Berlin, Germany (Lottermoser, 2012), respectively. In Africa, the lowest and highest amounts of Cu were found in the soils of Sadat, Egypt (Azzazy & Bhat, 2020) and Lagos, Nigeria (Isimekhai et al., 2017), while in Australia, the lowest and highest amounts of Cu were found in the soils of Melbourne (Kandic et al., 2019) and Sydney (Birch et al., 2011), respectively. In South America, the lowest and highest values of Cu were found in the soils of Manaus, Brazil (Ferreira et al., 2021) and Taltal, Chile (Reyes et al., 2020), while in North America, the lowest and highest values were obtained in the soils of Tampa, USA (da Silva et al., 2020) and Havana, Cuba (Rizo et al., 2011), respectively.

3.11. Zinc levels in urban soils across the world

The amount of Zn in Asian urban soils is between 1.14 mg/kg and 3370 mg/kg, while in European urban soils, its concentration is between 6.35 mg/kg and 3420 mg/kg. Its concentration in African urban soils is between 12.50 mg/kg and 3215.80 mg/kg, while in South American urban soils, its amounts are between 15.46 mg/kg and 766.82 mg/kg. In North American cities, the amount of Zn in soils is between 37 mg/kg and 663 mg/kg, while in Australia it is between 187 mg/kg and 218 mg/kg. Overall, the range of Zn in the soils of cities across the world is between 2.08 mg/kg and 12,986 mg/kg. The results showed that the average amounts of Zn were above their average crustal values (ACV) in 75% of the studied urban soils. The average distribution of Zn in urban soils across continents of the world is in the following order: Africa > Europe > Asia > Australia > North America > South America (Table 4). The lowest and highest values of Zn in urban soils across the world were reported in the soils of Bogota, Columbia (Donado et al., 2021) and Bangkok, Thailand (Damrongsiri et al., 2016) respectively. In Asia, the lowest and highest values of Zn were found in the soils of Zakamensk, Russia (Timofeev et al., 2018) and Bangkok, Thailand (Damrongsiri et al., 2016), while in Europe, the lowest and highest values were found in the soils of Ghent, Belgium (Delbecque & Verdoodt, 2016) and Berlin, Germany (Lottermoser, 2012). In Africa, the lowest and highest amounts of Zn were found in the soils of Sadat, Egypt (Azzazy & Bhat, 2020) and Kumasi, Ghana (Acheampong et al., 2016), while in Australia, the lowest and highest amounts were found in Manaus, Brazil (Ferreira et al., 2021) and Taltal, Chile (Reyes et al., 2020). In North America, the lowest and highest values of Zn were found in the soils of Orlando (da Silva et al., 2020) and Philadelphia (O'shea et al., 2021), respectively.

3.12. Iron levels in urban soils across the world

The amount of Fe in Asian urban soils is between 34.39 mg/kg and 88,531 mg/kg, while in European urban soils, its concentration is between 358 mg/kg and 56,350 mg/kg. Its concentration in African urban soils is between 119.89 mg/kg and 74,510 mg/kg, while in South American urban soils, its amounts are between 28.10 mg/kg and 56,508 mg/kg. In North American cities, the amount of Fe in soils is between 38,571 mg/kg and 52,000 mg/kg, while in Australia it is between 0 and 17,350 mg/kg. Overall, the range of Zn in the soils of cities across the world is between 28.10 mg/kg and 88,531 mg/kg. The results showed that the average amounts of Zn were above their average crustal values (ACV) in 16% of the studied urban soils. The average distribution of Fe in cities across continents is in the following order: North America > Africa > South America > Asia > Europe > Australia (Table 4). Across the world, the lowest and highest concentrations of Fe were found in the soils of Bogota, Columbia (Donado et al., 2021), and Bangkok, Thailand (Damrongsiri et al., 2016). In Asia, the lowest and highest amounts of Fe were recorded in the soils of Lianyuan, China (Liang et al., 2017) and Bangkok, Thailand (Damrongsiri et al., 2016), while in Europe, the lowest and highest values were found in the soils of Volos, Greece (Kelepertzis et al., 2021) and Sarajevo, Bosnia and Herzegovina (Sapcanin et al., 2017) each. In Africa, the lowest and highest amounts of Fe were found in the soils of Akure, Nigeria (Adewumi, 2022) and Kaft El-Zayat, Egypt (Shaheen et al., 2021), while in the soils of South America, the lowest and highest amounts of Fe were found in the soils of Bogota, Brazil (Donado et al., 2021) and Manaus, Brazil (Ferreira et al., 2021). In North America, the lowest and highest values were obtained in the soils of Moa (Diaz-Rizo et al., 2011) and Las Tunas, Cuba (Rodríguez-Oroz et al., 2018), respectively.

3.13. Degree of contamination by heavy metals across the world

The most commonly employed geochemical techniques used for calculating soil contamination were employed in this study. To get detailed information about the extent of heavy metal contamination of geological media, it is important to combine different geochemical methods. This is because a single contamination index may not provide facts about the degree of metal pollution in an area. For this reason, we evaluated the level of metal pollution in urban soils globally using the geo-accumulation index, contamination factor, contamination degree, and pollution load index. This study used the average crustal value of elements in soils as outlined by Rudnick and Gao (2003). The values of the geochemical background used by different authors in different cities may not be applicable in a world-wide review such as this. Also, since urban soils are part of the upper crust, it is best to compare the results obtained with the ACV.

3.14. Index of geoaccumulation (igeo)

The most commonly employed geochemical techniques used for calculating soil contamination were employed in this study. To get detailed information about the extent of heavy metal contamination of geological media, it is important to combine different geochemical methods. This is because a single contamination index may not provide facts about the degree of metal pollution in an area. For this reason, we evaluated the level of metal pollution in urban soils globally using the geo-accumulation index, contamination factor, contamination degree, and pollution load index. This study used the average crustal value of elements in soils as outlined by Rudnick and Gao (2003). The values of the geochemical background used by different authors in different cities may not be applicable in a world-wide review such as this. Also, since urban soils are part of the upper crust, it is best to compare the results obtained with the ACV.

3.15. Index of geoaccumulation (igeo)

Boxplots were used to visualize the index of geo-accumulation (Igeo) for metals in urban soils throughout the world (Figure 3). This was categorized based on continents and a combination of global calculations. In Africa, urban soils have *Igeo* values between − 2.48 (Addis Ababa, Ethiopia) and 1.75 (Toshki, Egypt) which reflected that city soils of Addis Ababa were uncontaminated by As while those of Toshki, Egypt were moderately polluted by the same metal. This study observed that the Igeo value for Pb in urban soils of Africa was between − 2.48 (Kumasi, Ghana) and 13.52 (Kinshasa, DR Congo), while for Hg it was between − 0.09 (Annaba, Morocco) and 6.49 (Ibadan, Nigeria). The Igeo for Cd is between − 2.16 (Sagamu, Nigeria) and 11.11 (Kumba, Cameroon), while for Cu it is between − 4.33 (Kumasi, Ghana) and 6.28 (Cairo, Egypt). The Igeo for Zn is between − 3.01 (Kumasi, Ghana) and 10.81 (Cairo, Egypt). This revealed that urban soils on the continent are unpolluted to extremely polluted by Pb, Hg, Cd, Cu, and Zn. Igeo for Ni is between − 3.43 (Annaba, Morocco) and 0.33 (Addis Ababa, Ethiopia), while for Cr it is between − 4.86 (Annaba, Morocco) and 0.94 (Sadat, Egypt), which reflects unpolluted to moderate pollution of the soils by these metals. The Igeo for Fe in urban soils of Africa is between − 9.30 (Kumba, Cameroon) and − 0.02 (Ibadan, Nigeria), which shows that they are unpolluted by the metal.

Igeo for As values in Asia range from 1.25 (Haikou, China) to 4.39 (Arak, Iran), indicating that urban soils are moderately to substantially contaminated with the element (Figure 3). Igeo for Pb is between − 3.48 (Ras Tunas, Saudi Arabia) and 7.82 (Kerman, Iran), while for Hg it is between − 0.58 (Longkou, China) and 11.21 (Lianyuan, China). *Igeo* for Cd is between − 0.43 (Riyadh, Saudi Arabia) and 10.25 (Rawalpindi, Pakistan), while for Ni it is between − 5.65 (Mumbai, India) and 5.15 (Beishan, China). For Cu, the Igeo is between − 4.19 (Taldykongma, Kazakhstan) and 8.27 (Bangkok, Thailand), while for Zn, it is between − 6.46

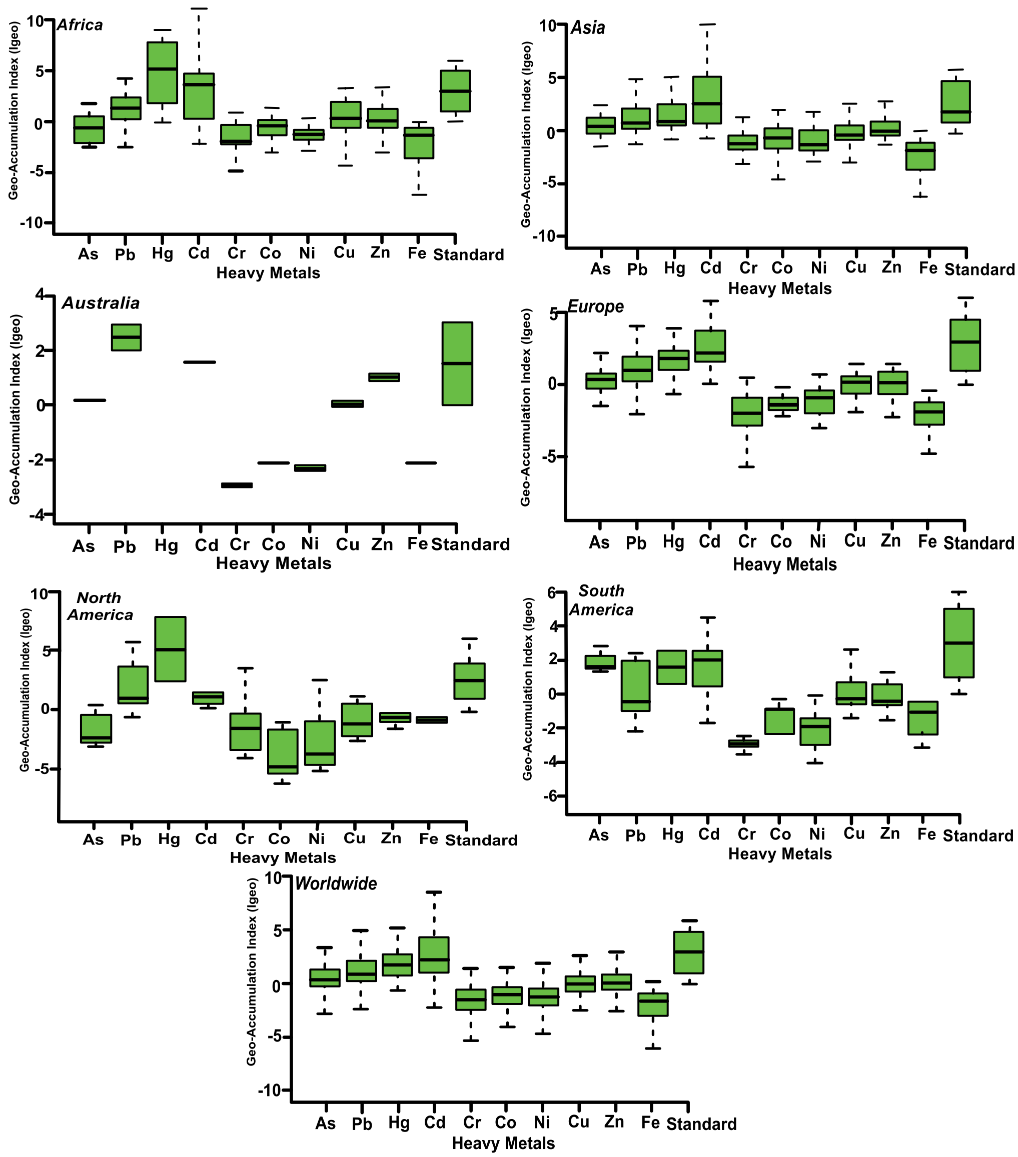

Figure 3. Geo-accumulation index (igeo) of heavy metals in urban soils.

(Ras Tunara, Saudi Arabia) and 5.07 (Bangkok, Thailand), respectively. This demonstrated how Pb, Hg, Cd, Ni, Cu, and Zn may poison soils across Asia in varying degrees. In addition, this study found that Igeo for Cr ranges from – 6.97 in Taldykongam, Kazakhstan, to 2.71 in Beishan, China, and for Co, it ranges from – 5.64 in Ras Tanura, Saudi Arabia, to 2.22 in Al Jubail, Saudi Arabia, indicating that urban soils on the continent are unpolluted to moderately polluted, respectively. The research also revealed that Igeo for Fe ranges from – 11.70 (Lianyuan, China) to 0.23 (Bangkok, Thailand). According to Igeo, urban soils in Australia are unpolluted by Cr, Co, Ni, and Fe but are lightly to moderately contaminated by As, Cd, Cu, and Zn. In Australia, urban soils are moderately to moderately heavily Pb-polluted.

In Europe, Igeo for As is between – 2.72 (Ghent, Belgium) and 3.47 (Pristina, Kosovo), while that for Hg is between – 0.58 (Lublin, Poland) and 3.95 (Ghent, Belgium) (Figure 3). This showed that European urban soils are unpolluted to heavily polluted by As and Hg. Also, Igeo for Pb is between – 2.03 (Ghent, Belgium) and 4.09 (Aliaga, Turkey), while that of Cu is between – 2.45 (Ghent, Belgium) and 4.92 (Berlin, Germany), which shows that the soils are unpolluted to extremely polluted by them. Igeo for Ni is between – 4.61 (Ghent, Belgium) and 0.76 (Kragu Jevac, Serbia), while for Cr it is between – 6.39 (Ghent, Belgium) and 0.48 (Lublin, Poland). These revealed that the urban soils are unpolluted to moderately polluted by Cr and Ni. Furthermore, Igeo for Cd is between 0.15 (Torun, Poland) and 7.86 (Berlin, Germany), which shows that they are unpolluted, moderately polluted, or extremely polluted by the metal. The Igeo for Zn is between – 3.98 (Ghent, Belgium) and 5.09 (Berlin, Germany), which indicates that the soils were unpolluted to extremely polluted by the metal. Igeo for Co is between – 2.13 (Bratislava, Slovakia) and – 0.19 (Kragu Jevac, Serbia), while for Fe it is between – 7.72 (Volos, Greece) and – 0.42 (Sarajevo, Bosnia and Herzegovina), which reflect that they are unpolluted by the metals.

Igeo for As values in North America range from – 2.92 (in Orlando, USA) to 4.11 (in Detroit, USA), indicating that soils there are either unpolluted or highly or excessively contaminated by the element. Igeo for Pb ranges from – 0.45 (in Orlando, USA) to 5.79 (in Detroit, USA), indicating varying levels of metal pollution. Igeo for Hg ranges from 2.42 (New York, USA) to 7.78 (Moa, Cuba) in urban soils of North America, indicating that the soils are moderately, heavily, or very contaminated by this metal. For Cd, the Igeo is between 0.25 (Orlando, USA) and 5.05 (Detroit, USA), which reflects that they are unpolluted, moderately polluted, or extremely polluted by this metal. The Igeo for Cr is between – 3.85 (Orlando, USA) and 3.56 (Moa, USA), which shows that the urban soils are unpolluted to heavily polluted by this metal. Igeo for Cu is between – 2.44 (Tampa, USA) and 1.16 (Las Tunas, Cuba), which shows that urban soils in North America are unpolluted to moderately polluted by this metal. Igeo values for Ni range from – 4.95 in Orlando, Florida, to 2.66 in Moa, Cuba, while those for Zn range from – 1.44 in Orlando, Florida, to 2.72 in Philadelphia, Pennsylvania, showing that township soils on the continent are either unpolluted or only lightly to moderately or heavily polluted by these two metals. Cobalt's Igeo ranges from – 5.98 in Orlando, Florida, to 2.66 in Moa, Cuba, while Fe's ranges from – 0.97 in Moa, Cuba, to – 0.53 in Las Tunas, Cuba, indicating that they are not contaminated by these metals.

In South America, Igeo for As is between – 2.29 (Quinto, Ecuador) and 2.82 (San Luis, Mexico), while for Pb it is between – 2.16 (Rio de Janeiro, Brazil) and 2.41 (Taltal, Chile). This showed that urban soils in South America are uncontaminated or moderately or highly polluted by As and Pb. For Zn, the Igeo is between – 1.52 (Manaus, Brazil) and 1.26 (San Luis, Mexico), which suggests that they are uncontaminated to moderately polluted by the metal. Also, Igeo for Cr, Co, Ni, and Fe is less than 0, indicating that these metals have contaminated the soil. The igeo for Hg in soils on this continent is between 0.42 (Bogota, Columbia) and 2.58 (San Luis, Mexico), which implies that they are uncontaminated or moderately polluted to moderately or heavily polluted by this metal. Globally, the Igeo for Pb is between – 3.49 (Ras Tunas, Saudi Arabia) and 7.82 (Kerman, Iran); Hg is between – 0.58 (Lublin, Poland) and 11.21 (Lianyuan, China); Cd is between – 2.17 (Addis Ababa) and 11.11 (Sagamu); Ni is between – 5.65 (Mumbai, India) and 5.18 (Beishan, China); for Cu is between – 4.33 (Sadat, Egypt) and 8.27 (Bangkok, Thailand); and for Zn is between – 6.46 (Ras Tunas Tunas, Saudi Arabia) and 5.09 (Berlin, Germany). This showed that across the world, urban soils are unpolluted to extremely polluted by Pb, Hg, Cd, Ni, Cu, and Zn. The Igeo for As ranges from – 2.99 (Orlando, USA) to 4.39 (Arak, Iran), indicating varying levels of metal pollution in local soils, from none at all to heavily or extremely contaminated. The results of this study also demonstrated that whereas urban soils across the world range from being unpolluted to substantially contaminated by Co, they range from being unpolluted to moderately or heavily polluted by Cr. Igeo has shown that Fe pollution levels in urban soils are low to moderate around the world. In Australia, Igeo research revealed that urban soils are unpolluted to moderately contaminated by Cr, Co, Ni, and Fe but moderately polluted by As and Cu. The urban soils are moderately and heavily polluted by Zn, respectively.

3.16. Contamination factor (CF), contamination degree (CD), and Pollution Load Index (PLI)

The urban soils of Asia were weakly to very highly contaminated by As (0.63–31.67), Pb (0.13–340), Cr (0.01–9.78), Co (0.03–6.99), Ni (0.03–54.46), Cu (0.08–463.78), and Zn (0.02–50.29) each, according to the contamination factor (CF) (Figure 4). Soils of Haikou, Ras Tunas, Taldykongam, and Mumbai are least contaminated by these metals, while soils of Arak, Kerman, Beishan, Al-Jubail, and Bangkok were the most affected by these metals. Also, the soils of this continent were moderately to highly contaminated by Hg and Cd, which have CFs 594 and 304 times higher than the maximum CF, respectively. The soils of Longkou and Riyadh were moderately contaminated by these metals, while those of Lianyuan and Rawalpindi were very highly contaminated by Hg and Cd, respectively. Urban soils in Asia were lowly to moderately contaminated by Fe. Amongst all these, Hg is the most dangerous metal that threatens the environment greatly. The contamination degree (CD) for soils on this continent is between 4.15 and 3579.49, which shows that they are lowly to very highly contaminated by heavy metals, with the lowest and highest values observed in soils in Ho Chi Minh City and Lianyuan, China, respectively. Urban soils in Asia have pollution load index (PLI) values of between 0.19 and 37.19, which confirm that they are unpolluted to highly polluted by heavy metals. PLI revealed that the soils of Ras Tunas, Saudi Arabia, are the least polluted by heavy metals, while those of Usthamenogorsk, Kazakhaztan, are the most polluted.

Urban soils in Europe with CF values of 0.23–16.61, 0.37–25.71, 0.27–45.36, and 0.09–51.05 for As, Pb, Cu, and Zn, respectively, showed that these soils are moderately to extremely polluted by these metals (Figure 4). Compared to Pristina, Aliaga, and Berlin, the soils of Ghent are only moderately polluted with these metals. Hg and Cd, with CF values of 1–23.20 and 1.67–350, respectively, are moderately to extremely heavily polluted urban soils on this continent. In this region, the soils of Lublin and Torun are somewhat polluted, while those of Ghent and Berlin are both very contaminated. Urban soils in this region exhibit CF values for chromium, cobalt, nickel, and iron of 0.02–2.09, 0.34–1.31, 0.06–2.56, and 1–1.12, respectively, indicating low to moderate metal contamination. The soils of Ghent, Bratislava, and Volos are lowly contaminated by these metals, while those of Lublin, Kragujevac, and Sarajevo are moderately contaminated by these metals. Also, CD uncovered that cities soils in Europe are generally lowly to very highly contaminated by heavy metals, with the lowest recorded in those of Ghent and the highest found in those of Berlin. This is also corroborated by PLI, with values between 0.43 (Gent) and 16.51 (Berlin).

In Africa, As has CF values of 0.26–5.05, with the lowest and highest values found in the soils of Kinshasa and Mojo, respectively (Figure 4). This revealed that urban soils in Africa are lowly to considerably contaminated by this metal. Also, township soils in this region have CFs of 0.27–142.24, 0.33–3321, 0.07–117.04, and 0.19–47.99 for Pb, Cd, Cu, and Zn, respectively. The lowest values, which reflect low contamination, are found in soils in Sadat and Addis Ababa, while the highest values, which connote very high contamination, are found in soils in Lagos, Sagamu, and Kumasi. Cobalt in urban soils in this region has a CF between 0.07 and 3.94, with the lowest and highest values recorded in soils in Sadat and Kumasi, respectively. This demonstrated how heavily to very heavily polluted the soils in this area are by these metals. Additionally, the CF for Ni and Fe in African city soils ranges from 0.14 to 1.88 and 1 to 1.48, with the lowest values being discovered in Ijero and Akure, respectively, and the greatest values being found in Kaft El-Zayat. On African soils, the CF for mercury ranges from 1.40 in Ijero, Nigeria, to 768 in Port-Harcourt, both countries. This demonstrated the degree to which this metal is polluted in the soils of this area. While PLI (0.18–23.20) revealed that the soils are significantly polluted by heavy metals, contamination degree (1.54–3367.69) indicated that they are weakly to very highly contaminated by heavy metals. Australia's Melbourne and Sydney soils were found by CD to have low levels of Cr, Co, Ni, and Fe contamination, respectively, but As and Cu contamination were considerable. Zn contamination in the soils of this area ranges from mild to significant, but Pb contamination is quite high. While PLI revealed that they are heavily polluted, contamination degree revealed that the soils of Melbourne and Sydney are moderately to significantly contaminated by heavy metals.

The CF values for As, Pb, Cd, and Cu in South America are 0.31–10.63, 0.34–7.95, 0.40–33, and 0.52–3.58, respectively, indicating that the region is moderately to extremely polluted by these metals (Figure 4). While San Luis and Taltal have relatively high levels of contamination, Quinto, Rio de Janeiro, and Manaus have minimal levels of contamination. Additionally, Hg in these soils has a CF of 2 to 9 for soils in Bogota and San Luis, indicating that they are moderately to very heavily polluted by this metal. In these soils, cobalt and nickel had CF ranging from 0.03 to 1.19 and 0.09 to 1.40, respectively. Co and Ni contamination in the soils of Manaus and Quinto is minimal, but it is high in Taltal and Havana. Zinc has CF values ranging from 0.52 to 3.58, indicating that the soils in this region are lightly to moderately polluted with the metal. Additionally, Rio de Janeiro and San Luis soils' CD values ranged from 3.28 to 59.14, indicating a low to extremely high level of hazardous metal contamination. PLI values for metals in the soils of the region range from 0.38 to 11.85 for soils in Rio de Janeiro and San Luis, respectively, indicating that they are either unpolluted or extremely severely contaminated by heavy metals.

Urban soils in North America have CF values for As, Cr, Ni, and Zn between 0.19 and 25.89, 0.10 and 17.73, 0.05 and 9.47, and 0.55 and 9.89, respectively, indicating that these metals are present in low to extremely high concentrations (Figure 4). The soils of Orlando are lowly contaminated by these metals, while those of Detroit, Moa, and Philadelphia are very highly contaminated by these metals. Also, in the soils of this region, CF is between 1.10–83.50 and 1.77–50 for Pb and Cd, respectively. This showed that the soils of Orlando are moderately contaminated by this metal, while those of Detroit and Las Tunas are very highly contaminated by it. Mercury in urban soils in this region has a CF between 8 and 330, with the lowest and highest values found in soils in New York and Detroit, respectively. This clearly showed they were totally and highly contaminated by this metal. Cobalt in the soils of Orlando and Moa has CF values of between 0.02 and 0.81, which suggests that they are lowly contaminated by the metal. The CF for Cu in the soils of this region is between 0.28 and 3.36, with the lowest and highest values obtained in Tampa and Las Tunas, respectively. This showed that the soils of this area are lowly to considerably

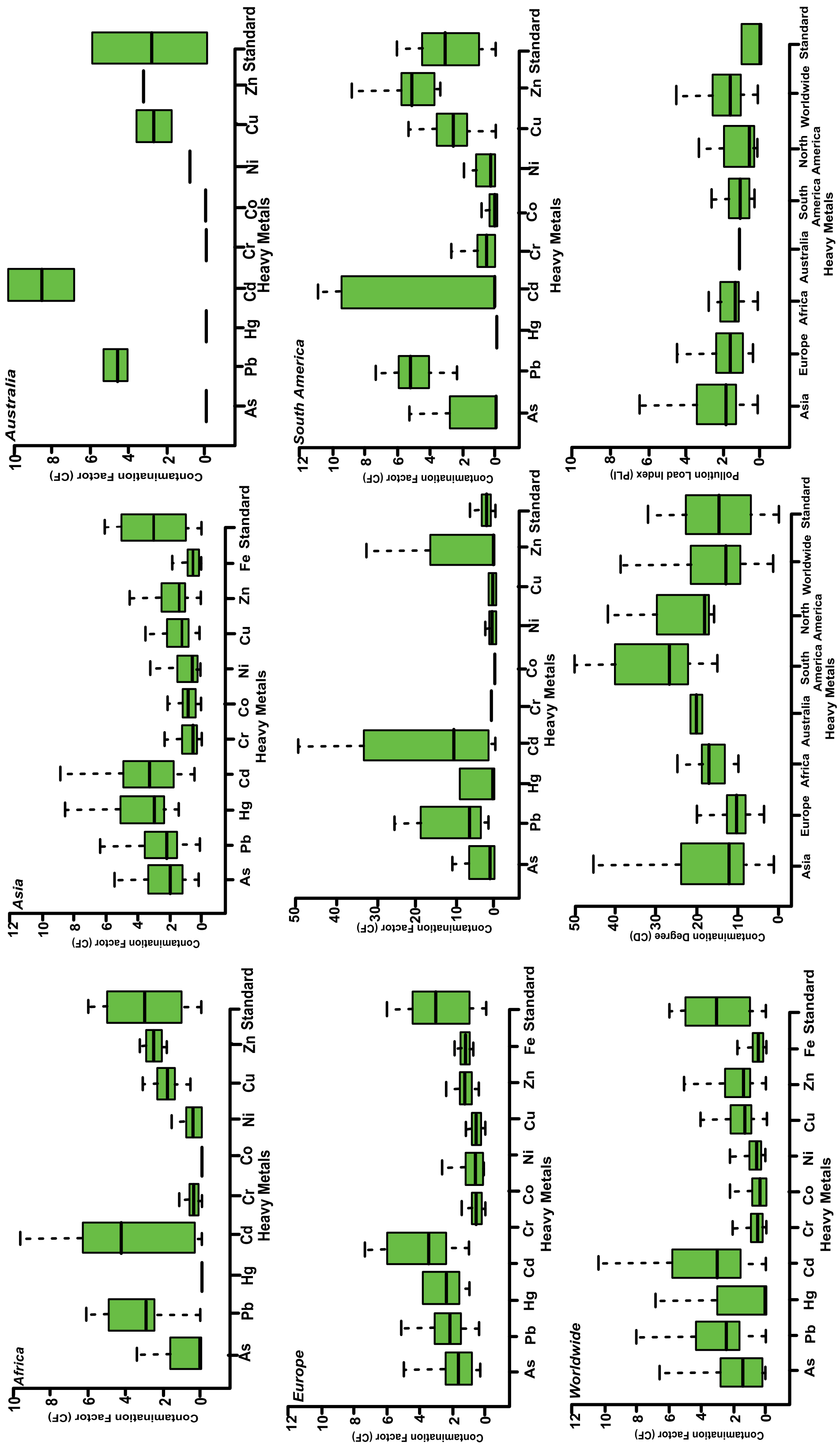

Figure 4. Contamination factor, contamination degree and pollution load index of metals in urban soils.

contaminated by these metals. Fe in the soils of this region has CF values of 0.77–1.03, with the lowest and highest values recorded in Moa and Las Tunas, respectively. This showed that the region's soils are only mildly to moderately polluted with these metals. The CD values for the metals in the soils of this region range from 4.15 to 496.10, as measured in Detroit and Orlando, respectively. This reflected the fact that the soils of Orlando and Detroit are lowly and very highly contaminated by heavy metals, respectively. PLI values range from 0.23 to 26.61, with the lowest and highest values found in the soils of Pensacola and New York, respectively. This showed the soils of Pensacola and New York are unpolluted and highly polluted by metals, respectively.

Globally, this study showed that As, Pb, Cd, Cr, Co, Ni, Cu, and Zn have CF values of 0.19–31.67, 0.13–340, 0.33–3321, 0.01–17.73, 0.02–6.97, 0.03–54.47, 0.07–463.79, and 0.02–51.04 in urban soils (Figure 4). It showed that the soils of Orlando, Ras Tunas, Addis Ababa, Taldykongam, Mumbai, and Sadat are lowly contaminated by these metals, while those of Arak, Kerman, Sagamu, Moa, Al-Jubail, Beishan, Bangkok, and Berlin are very highly contaminated by these metals. Also, the study revealed that the CF values for Hg are between 1 and 3563.8, while for Fe they are between < 1 and 1.76, respectively. This showed that the soils of Lublin and Longkou are lowly contaminated by Hg, while those of Lianyuan are highly contaminated by the metal. Also, the soils of Bogota are lowly contaminated by Fe, while those of Bangkok are highly contaminated by it. The CD values of heavy metals in urban soils worldwide range from 1.54 to 3579.49, indicating that they are moderately to severely polluted. Globally, the least and most polluted soils are found at Lianyuan and Sadat, respectively. PLI values range from 0.18 to 37.19, indicating varying levels of heavy metal pollution in urban soils. The lowest and highest values were found in the soils of Usthamenogorsk, Kazakhstan, and Sadat, Egypt, respectively.

3.17. Heavy metal sSources in urban soils

Heavy metals in urban soils originate from many sources, which can be classified as geogenic, or natural, and anthropogenic, or human-related. This study revealed that sources of toxic metals in the soils of cities include:

(1) **Increased industrialization**: Industrial setups play a key role in the release of metals into urban soils. In many cities across the world, industries such as vehicles, iron and steel, petrochemicals, electronics, building, textiles, autoparts, tanneries, paint, power plants, petroleum, cement, wood, and food processing are common sources of metals in soils. These are common in cities such as Xiamen, Dongguan, Xi'an, Ulaanbaatar, Ningbo, Rawalpindi, Gujranwala, Shaoxing, Zunyi, Lanzhou, Kathmandu, Ust-Kamenogorsk, Lahore, Delhi, Haikou, Ahvaz, Longkhou, Ghazibad, Beijing, Shanghai, Taiyuan, Kerman, Zhangzhou, Mojo, Sadat, Port-Harcourt, Cape Town, Lagos, Ibadan, Sagamu, Moa, Las Tunas, Manaus, Novi Sad, Lublin, Aviles, Salzburg, Thessaloniki, Belgrade, Dublin, Krakow, Warszawa, Wroclow, Ghent, Murcia, Ras Tanura, Athens, Paris, Istanbul, Aliaga, Philadelphia, Detroit, New York City, (Kolawole et al., 2022, Shezi et al., 2022, Howard et al., 2019, Huang et al., 2019, Zhang et al., 2019, Olatunde & Onisoya, 2017, Isimekhai et al., 2017, Adamiec, 2017, Bhatia et al., 2015, Ogunkunle & Fatoba, 2014, Glennon et al., 2014).

(2) **Urbanization**: with an increase in the number of industries, more people move into cities with the hope of getting a better life. This led to the expansion of cities and thus human activities, which in turn led to an increase in metals in the environment. This is typical of cities such as Rawalpindi, Delhi, Ghazibad, Taiyuan, Kerman, Zhangzhou, Kumba, Yaoundé, Akure, Toshki, Port-Harcourt, Lagos, Ibadan, Manaus, Bratislava, Salzburg, Thessaloniki, Belgrade, Paris, Istanbul, Ulcinj, Detroit, New York City, Sydney, and Melbourne. (Adewumi, 2022; Aboubakar et al., 2021; Pavlovic *et al.* 2021; Huang et al., 2021; Kandic et al., 2019; Burt et al., 2014; Igbal *et al.* 2012; Birch et al., 2011).

(3) **Geogenic sources**: Rocks are naturally made up of minerals and metals. The breaking down of rocks through processes such as weathering facilitates metal mobility through soils in urban areas. This was observed in cities such as Dongguan, Xi'an, Ningbo, and Quito (Bonilla-Bedoya et al., 2021, Tian et al., 2020, Xiang et al., 2020, Zhang et al., 2019).

(4) **Vehicular exhausts**: High vehicular movements in cities release large amounts of exhaust into the environment. The exhausts contain high amounts of metals such as Pb, which settle and interact with urban soils. Examples are seen in cities such as Xi'an, Lanzhou, Kathmandu, Shanghai, Haikou, Kerman, Akure, Ibadan, Lagos, Manaus, Novi Sad, Ghent, Murcia, Paris, and Philadelphia. (O'shea et al., 2021; Bi et al., 2020; Li et al., 2020; Yadav et al., 2019; Bi et al.,

2018; Foti et al., 2017; Skrbic and Durisic-Mladenovic 2013).

(5) **Industrial waste**: Any material that is rendered unusable during a production process is regarded as industrial waste. This is typical of Ulaanbaatar, Mojo, and Lagos (Bilguun et al., 2020; Gebeyehu and Bayissa 2020; Isimekhai et al., 2017).

(6) **Wastewater**: Water generated from industries and homes in cities may contain an appreciable amount of metals that interact with soils. This is exemplified by the release of metals from wastewater into the soils of Kana Sura, Kani Kolka, and Xiangtan (Hawrami et al., 2020, Deng et al., 2019).

(7) **Mining**: The extraction of minerals from rocks is a major source of heavy metals in soils. This is common in soils in Anhui, Yulin, Ust-Kamenogorsk, Longkhou, Fuxin, Obuasi, Ijero-Ekiti, Taltal, Copiapo, Rome, and Pristina. (Ramazanova et al., 2021, Reyes et al., 2020, He et al., 2020, Jianfei et al., 2020, Laniyan & Adewumi, 2020, Li et al., 2019, Montereali et al., 2017, Gulan et al., 2017, Bempah & Ewusi, 2016, Carkovic et al., 2016, Chen et al., 2015).

(8) **Waste management**: Another significant source of metals in soils, particularly in developing nations, is waste produced by human activity in cities. Cities like Ulaanbaatar, Shanghai, Kinshasa, Sadat, Manaus, Pisa, Paris, and Florida all display this (Mavakala et al., 2022; Ferreira et al., 2021; Bilguun et al., 2020; Azzazy 2020; da Silva et al., 2020; Foti et al., 2017; Bi et al., 2018; Bretzel & Calderisi, 2011).

(9) **Agricultural activities**: Agricultural procedures that involve the use of herbicides, insecticides, and fertilizers also contribute to the buildup of heavy metals in urban soils. Gujranwala, Ahvaz, Fuxin, Zhangzhou, Yaoundé, Cape Town, and Novi Sad all have urban soils where this has been seen (Shezi et al., 2022; Aboubakar et al., 2021; Huang et al., 2021; Keshavarzi et al., 2019; Yousef *et al.* 2016; Chen et al., 2015; Skrbic and Durisic-Mladenovic 2013).

3.18. Ecological risks of heavy metals in urban soils

Ecological risk assessment of toxic metals helps evaluate the extent to which they can affect the environment and ecosystem (Adewumi et al., 2022). In urban soils in Asia, it was observed that Hg has the highest ER while Cr has the lowest ER values. The potential ecological risk index (PERI) revealed that urban soils on this continent pose a slight to high ecological risk, aggravated by the presence of As, Pb, Hg, Cd, Ni, Cr, and Zn. In the cities of Arak and Zakamensk, the presence of As in soils is a major threat to the ecosystem, while in the soils of Ustkamenogorsk, Tehran, Rawalpindi, Lahore, Hyderabad, Changchun, and Bangkok Pb, it poses a major challenge to the ecosystem. Also, on this continent, Hg in urban soils poses a major problem to ecosystems in cities such as Suzhou, Shanghai, Ningbo, Lianyuan, Delhi, and Calcutta, while the presence of Cd in the soils poses major challenges in Ahvaz, Al-Jubail, Babao, Balkhash, Bijie, Bogoa, Calcutta, Changchun, Dhaka, Dongguan, Jiyan, Lahore, Mumbai, Ras Tunas, Rawalpindi, Ridder, Shymkent, Sialkot, Tehran, Uslan, Ust-Kamengersk, Xiangtan, and Zakamengersk. In Europe, Hg and Cd pose a great threat to urban soils. On this continent, PERI revealed that heavy metals in urban soils pose a slight to high ecological risk, aggravated by the presence of Hg and Cd. Mercury poses the highest ecological risk in the soils of Novi Sad, Aviles, Dublin, Ghent, and Aliaga, while Cd poses the highest ecological risk in the soils of Moscow, Novi Sad, Lublin, Aviles, Ghent, Paris, Kotor, Berlin, Aliaga, and Veles. Copper poses the highest ecological risks in the soils of Berlin (Table 5). According to PERI research, hazardous metals in urban soils in Africa offer a low to high ecological danger. Lead, Hg, Cd, and Cu pose the highest ecological risks in urban soils. Lead is a major threat to the soils of Kumasi, Ibadan, and Lagos, while HG poses major challenges to the soils of Obuasa, Port Harcourt, and Mojo. Cadmium also portends a major problem in the soils of Kumba, Port Harcourt, Harare, Akure, Ibadan, Mojo, Sagamu, Lagos, and Kinshasa, while Cu poses the highest ecological risks in the soils of Lagos (Table 5). In Australia, PERI revealed that heavy metals in urban soils pose a slight to medium ecological risk. In South America, PERI showed that metals in city soils pose a slight to high ecological risk, with Hg being a major threat to the soils of San Luis and Cd being a major problem in the soils of Manaus, Buenos Aires, and San Luis. In North America, PERI uncovered that metals in urban soils pose a slight to high ecological risk. Arsenic is a major problem for the soils of Detroit, while Pb poses a great problem for those of Detroit and Los Angeles. Mercury in the soils of Detroit and New York poses the highest ecological risks, while Cd in the soils of Detroit, New York, and Ocala portend the same challenge (Table 5).

Globally, the ER for As in urban soils is between 1.97 and 316.66, which reflects that they pose a slight to higher ecological risk in towns such as San Luis, Pristina, Detroit, Zakamensk, and Arak (Table 5). Lead in urban soils around the world has an ER between 0.67 and 1700, which shows that the metal poses the slightest

Table 5. Ecological risk (ER) and potential ecological risk index (PERI) of toxic metals in urban soils across the world

		ER As	ER Pb	ER Hg	ER Cd	ER Cr	ER Co	ER Ni	ER Cu	ER Zn	PERI
Asia	Minimum	6.31	0.67	40	33.33	0.02	0.15	0.15	0.41	0.02	18.68
	Maximum	316.67	1700.00	142552.00	54633.33	8.69	34.98	272.34	2318.93	50.29	142800.50
	Average	41.90	83.42	8429.20	3764.04	0.26	8.09	10.11	45.34	3.73	5024.94
Europe	Minimum	2.27	1.84	40.00	50.00	0.04	1.71	0.31	1.37	0.09	28.44
	Maximum	166.13	128.53	928.00	10500.00	4.17	6.53	12.78	226.78	51.04	10888.27
	Average	21.94	25.76	297.33	787.62	1.05	3.29	4.37	13.62	3.88	742.25
Africa	Minimum	2.68	1.34	56.00	10.00	0.10	0.36	0.69	0.37	0.19	5.10
	Maximum	50.58	711.18	30720.00	99633.33	5.76	19.71	9.40	585.18	47.99	99850.12
	Average	16.07	67.19	9262.00	7553.75	1.62	6.66	3.45	44.16	6.19	7300.44
Australia	Minimum	0	30.00	-	0	0.37	0	1.38	8.21	2.79	59.03
	Maximum	16.67	57.06	-	133.33	0.41	1.73	1.59	7.14	3.25	204.93
	Average	8.34	43.53	-	66.67	0.39	0.865	1.485	7.675	3.02	131.98
South America	Minimum	3.06	1.68	80.00	13.33	0.07	0.16	0.46	2.76	0.52	15.27
	Maximum	106.25	39.79	360.00	1000.00	35.47	5.95	47.34	136.93	3.35	1497.23
	Average	53.21	13.93	176.80	324.17	3.12	3.07	5.66	19.59	1.81	346.46
North America	Minimum	1.98	5.50	320.00	53.33	0.21	0.12	0.21	1.38	0.55	41.91
	Maximum	258.96	417.65	13200.00	1500.00	4.49	4.05	22.18	16.79	9.89	15403.27
	Average	37.49	90.62	6760.00	316.67	1.37	1.01	3.63	7.07	2.15	1618.54
Overall	Minimum	1.98	0.67	40.00	10.00	0.02	0.12	0.15	0.37	0.02	5.10
	Maximum	316.67	1700.00	142552.00	99633.33	35.47	34.98	272.34	2318.93	51.05	142800.50
	Average	36.17	60.87	5445.13	2893.09	1.91	5.38	6.98	32.03	3.83	3547.44

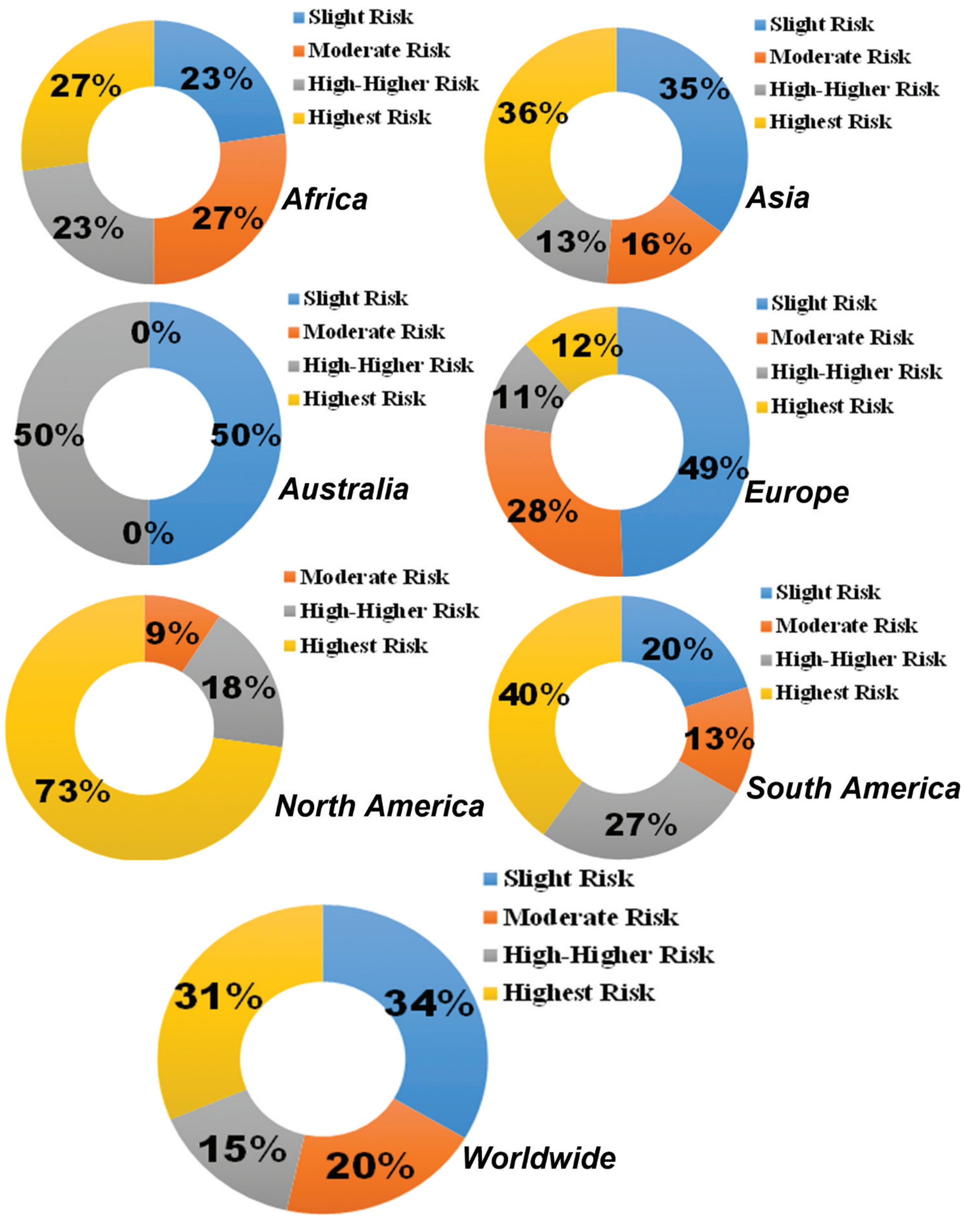

Figure 5. Percentage distribution of potential ecological risk index of heavy metals in urban soils across the world.

to highest ecological risks in cities such as Detroit, Rawalpindi, Lagos, Changchun, Bangkok, and Kerman. The ER for Hg in global urban soils is between 40 and 142,552, which also reflects that the metal poses slight to highest ecological risks in cities such as Jiyan, Aliaga, San Luis, Shanghai, Suzhou, Ningbo, Aviles, Obuasa, Ghent, Calcutta, Mojo, Detroit, Delhi, Port Harcourt, and Lianyuan. Similarly, the ER for Cd in global urban soils is between 10 and 99,633, which also shows that the metal poses slight to highest ecological risks in cities such as Berlin, Calcutta, Sialkot, Zakamensk, Ras Tunas, Hyderabad, Al-Jubail, Mumbai, Dongguan, Rawalpindi, Sagamu, Lahore, Lagos, Port Harcourt, and Dhaka. The ER for Cr and Co in global urban soils is between 0.02–35.67 and 0.12–34.96, which reflects that these metals only pose a slight ecological risk. The ER for Ni in urban soils across the world is between 0.15 and 272.34, which shows that the metal poses a slight to higher ecological risk in cities such as Beishan. The ER for Cu in global urban soils is between 0.37 and 2318.93, which shows that it poses slight to high ecological risks in cities such as Berlin, Lagos, and Bangkok. Worldwide, the ER for Zn is between 4.96 and 51.04, which reflects that it poses a slight to medium ecological risk. Overall, PERI revealed that metals in 34% of the global urban soils pose slight ecological risks in cities such as Sadat, Quinto, Salzburg, Addis Ababa, Tampa, Haikou, and Tianjin, while in

20% of the cities covered in this study they pose moderate ecological risks in cities such as Sydney, Chongqing, Zagreb, Philadelphia, Cairo, Los Angeles, and Krakow (Figure 5). The study also shows that heavy metals in the soils of 15% of cities studied pose higher ecological risks in cities such as Hyderabad, Wroclaw, Beishan, Guiyang, Pristina, New York, Shanghai, Islamabad, Buenos Aires, and Volvos. Of the global urban soils captured, heavy metals in 31% of the cities pose the highest ecological risks in cities such as Bogota, Harare, Moscow, Akure, Kinshasa, Ibadan, Paris, Obuasa, Dublin, Los Angeles, San Luis, Tehran, Gent, Kerman, Jiyan, Veles, Aliaga, Aviles, Bangkok, Lahore, Lagos, Ras Tanura, Zakamensk, Detroit, Mumbai, Port Hacourt, Rawalpindi, Sagamu, and Lianyuan (Figure 5).

Various heavy metals have different environmental effects. Lethality, growth suppression, photosynthesis and reproduction inhibition, and behavioral consequences are only a few of the effects of As on the environment. There are fewer species and less variety when there is an abundance of As (Gomez-Caminero et al., 2001). Reduced development and reproduction in both plants and animals, as well as neurological problems in vertebrates, are caused by an environment that contains more lead (USEPA, 2022). Mercury can cause plants to grow more slowly and produce less (Gworek et al., 2020). Additionally, it interferes with photosynthetic processes, leads to nutritional imbalances, is genotoxic, and lowers chlorophyll levels (Khalid et al., 2020). Cadmium alters the photosynthetic machinery and prevents the use, absorption, and transport of vital nutrients and water, which causes the death of plant tissue (Qadir et al., 2014).

3.19. Human health risks of heavy metals in urban soils

Human health risk assessment (HHRA) is an evaluation of the type and likelihood of harmful health consequences for humans who may be exposed to chemicals in polluted environmental media, either now or in the future (Jaishankar et al., 2014). This method has been used by many researchers, such as Ngole-Jeme et al. (2017), Song et al. (2015), Edin et al. (2020) and Adewumi et al. (2020), to estimate the extent to which toxic metals could affect human health. According to this study, children's daily intake of heavy metals from urban soils poses non-carcinogenic health risks of 1.4E +2 mg/kg/day, 6.8E−7 mg/kg/day, and 2.8E−2 mg/kg/day through oral ingestion, inhalation, and dermal contact, respectively, while posing carcinogenic health risks of 3.1E−1 mg/kg/day, 5.9E−8 mg/kg/day, and 2.5E−3 mg/kg/day (Table 6). Adults' total daily intake of heavy metals from urban soils for non-carcinogenic health risks is 4.9E−1 mg/kg/day, 7.3E−7 mg/kg/day, and 2.1E−2 mg/kg/day, respectively, whereas it is 1.7E−1 mg/kg/day, 2.5E−7 mg/kg/day, and 7.2E−3 mg/kg/day for carcinogenic health risks (Table 6). This research shows that while adults are more likely to inhale heavy metals from urban soils, children are more likely than adults to absorb heavy metals into their systems through skin contact and ingestion for both non-carcinogenic and carcinogenic health hazards.

The outcomes of the analysis of non-carcinogenic health risks for both children and adults are presented in Figure 6. In this study, results of the analysis of non-carcinogenic substances showed that the hazard quotient (HQ) for all cities was greater than 1 for children (Figure 6). As, Pb, Hg, Cd, Cr, Co, Ni, and Cu are the driving forces for high HQ for non-carcinogenic health hazards. The highest HQ values are for chromium, which is followed by Pb, Cu, and Cd. The WHO limit for the HQ of heavy metals for non-carcinogenic health risks is approximately 200 times higher (USEPA 2002). Inhalation and dermal contact with heavy metals had HQs of less than 1, indicating that these are not the main routes via which non-carcinogenic health concerns may harm children in cities around the world. The total hazard index (HI) for non-carcinogenic health risks for children is > 1, which indicates that children are prone to these diseases via oral intake. For adults, HQ through oral intake of Pb in urban soils is > 1 for the cities of Bangkok, Changchun, Kerman, and Lagos, while HQ through dermal contact with Cd, Cr, and Co is > 1 in the soils of Rawalpindi, Sagamu, Beishan, Moa, Al-Jubail, and Bogoa. The HQ of metals through inhalation is < 1. For adults, HI is > 1 for metals in the soils of Al-Jubail, Arak, Babio, Bangkok, Beishan, Bogoa, Changchun, Dongguan, Hyderabad, Kathmandu, Kerman, Lianyuan, Mumbai, Rawalpindi, Sialkot, Tehran, Ulaanbaatar, Zakamensk, Kumasi, Sagamu, Lagos, Moa, and Detroit. This showed that grownups in these cities are liable to non-carcinogenic health risks through oral ingestion of Pb and dermal contact with Cd, Cr, and Co in urban soils. The study further showed that HQ values for kids are higher compared to those of adults (Figure 6). This shows that children in cities are more susceptible to non-carcinogenic health concerns than adults, particularly when ingested orally. In addition, Adewumi et al. (2020) have made this claim.

In this investigation, the HQ for children's exposure to carcinogenic health hazards from As, Pb, Cr, and Ni was > 1E−4. In urban soils, HQ for As is > 1E−4 in 71 cities, whereas HQ for Pb is greater in 50 cities. Additionally, the HQ for Cr is greater in the soils of 127 cities than it is in the soils of 130 cities for Ni. The soils of Arak, Kerman,

Table 6. Average daily intake (ADI) of heavy metals through oral consumption, inhalation, and skin contact with urban soils (mg/kg/day)

				As	Pb	Hg	Cd	Cr	Co	Ni	Cu	Zn	Fe	Total
Child	Non Carcinogenic	ADIing	Minimum	1.2E–4	2.9E–4	6.4E–6	3.0E–2	2.0E–1	1.6E–2	5.2E–5	2.7E–4	1.5E–4	3.6E–3	2.6E–1
			Maximum	1.9E–2	7.4E–1	2.3E–2	3.8E–6	1.4E–1	5.2E–5	1.6E–2	1.7E + 0	4.4E–1	1.1E + 1	1.4E + 2
			Average	**2.2E–3**	**2.6E–2**	**8.7E–4**	**2.7E–8**	**1.1E–2**	**2.4E–3**	**1.3E–3**	**2.3E–2**	**3.3E–2**	**3.5E + 0**	**1.4E + 2**
		ADIinh	Minimum	2.3E–11	5.5E–11	1.2E–12	7.2E–13	2.7E–11	9.9E–12	3.4E–11	5.0E–11	2.8E–11	6.8E–10	9.1E–10
			Maximum	3.7E–9	1.4E–7	4.3E–9	7.2E–9	3.9E–8	2.9E–9	6.2E–8	3.1E–7	8.3E–8	2.1E–6	2.8E–6
			Average	**4.2E–10**	**5.0E–9**	**1.6E–10**	**2.1E–10**	**2.1E–9**	**4.5E–10**	**1.6E–9**	**4.3E–9**	**6.2E–9**	**6.6E–7**	**6.8E–7**
		ADIderm	Minimum	9.7E–7	2.3E–6	5.1E–8	3.1E–8	1.1E–6	4.2E–7	1.4E–6	2.1E–6	1.2E–6	2.9E–5	3.8E–5
			Maximum	1.6E–4	5.9E–3	1.8E–4	3.1E–4	1.7E–3	1.2E–4	2.6E–3	1.3E–2	3.4E–3	9.1E–2	1.2E–1
			Average	**1.7E–5**	**2.1E–4**	**6.9E–6**	**8.9E–6**	**8.9E–5**	**1.9E–5**	**6.7E–5**	**1.8E–4**	**2.6E–4**	**2.8E–2**	**2.8E–2**
	Carcinogenic	ADIing	Minimum	1.0E–5	2.4E–5	5.5E–7	3.3E–3	1.2E–5	4.5E–6	1.5E–5	2.3E–5	1.3E–5	3.1E–4	3.7E–3
			Maximum	1.7E–3	6.3E–2	1.9E–3	3.3E–7	1.8E–2	1.3E–3	2.8E–2	1.4E–1	3.8E–2	9.7E–1	1.3E + 0
			Average	**1.9E–4**	**2.2E–3**	**7.5E–5**	**9.5E–5**	**9.6E–4**	**2.0E–4**	**7.2E–4**	**1.9E–3**	**2.8E–3**	**3.0E–1**	**3.1E–1**
		ADIinh	Minimum	1.9E–12	4.7E–12	1.0E–13	6.2E–14	2.3E–12	8.5E–13	2.9E–12	4.3E–12	2.4E–12	5.8E–11	7.8E–11
			Maximum	3.2E–10	1.2E–8	3.7E–10	6.2E–10	3.4E–9	2.5E–10	5.3E–9	2.7E–08	7.1E–9	1.8E–7	2.4E–7
			Average	**3.6E–11**	**4.3E–10**	**1.4E–11**	**1.8E–11**	**1.8E–10**	**3.9E–11**	**1.4E–10**	**3.7E–10**	**5.3E–10**	**5.7E–8**	**5.9E–8**
		ADIderm	Minimum	8.3E–8	1.9E–7	4.4E–9	2.6E–9	9.6E–8	3.6E–8	1.2E–7	1.8E–7	9.9E–8	2.5E–6	3.3E–6
			Maximum	1.3E–5	5.0E–4	1.6E–5	2.6E–5	1.4E–4	1.1E–5	2.2E–4	1.1E–3	3.0E–4	7.8E–3	1.0E–2
			Average	**1.5E–6**	**1.8E–5**	**5.9E–7**	**7.6E–7**	**7.7E–6**	**1.6E–6**	**5.8E–6**	**1.6E–5**	**2.3E–5**	**2.4E–3**	**2.5E–3**
Adult	Non-Carcinogenic	ADIing	Minimum	1.6E–5	3.9E–5	8.6E–7	5.2E–7	1.9E–5	7.0E–6	2.4E–5	3.6E–5	1.9E–5	4.8E–4	6.4E–4
			Maximum	2.6E–3	9.9E–2	3.1E–3	5.1E–3	2.8E–2	2.1E–3	4.4E–2	2.2E–1	5.9E–2	1.5E + 0	1.9E + 0
			Average	**2.9E–4**	**3.6E–3**	**1.2E–4**	**1.5E–4**	**1.5E–3**	**3.2E–4**	**1.1E–3**	**3.1E–3**	**4.4E–3**	**4.7E–1**	**4.9E–1**
		ADIinh	Minimum	2.4E–11	5.9E–11	1.3E–12	7.8E–13	2.7E–11	1.1E–11	3.6E–11	5.4E–11	2.9E–11	7.3E–10	9.8E–10
			Maximum	3.9E–9	1.5E–7	4.6E–9	7.8E–9	4.2E–8	3.2E–9	6.7E–8	3.9E–7	8.9E–8	2.3E–6	3.0E–6
			Average	**4.5E–10**	**5.4E–9**	**1.8E–10**	**2.3E–10**	**2.3E–9**	**4.8E–10**	**1.7E–9**	**4.7E–9**	**6.7E–9**	**7.1E–7**	**7.3E–7**
		ADIderm	Minimum	7.1E–7	1.7E–6	3.7E–8	2.2E–8	8.2E–7	3.1E–7	1.0E–6	1.6E–6	8.5E–7	2.1E–5	2.8E–5
			Maximum	1.1E–4	4.3E–4	1.3E–4	2.2E–4	1.2E–3	9.0E–5	1.9E–3	9.7E–3	2.6E–3	6.6E–2	8.6E–2
			Average	**1.3E–5**	**1.5E–4**	**5.1E–6**	**6.5E–6**	**6.5E–5**	**1.4E–5**	**4.9E–5**	**1.3E–4**	**1.9E–4**	**2.0E–2**	**2.1E–2**
	Carcinogenic	ADIing	Minimum	5.5E–6	1.3E–5	2.9E–7	1.8E–7	6.5E–6	2.4E–6	8.2E–6	1.2E–5	6.7E–6	1.7E–4	2.2E–4
			Maximum	8.9E–4	3.4E–2	1.1E–3	1.8E–3	9.6E–4	7.1E–4	1.5E–2	7.6E–2	2.0E–2	5.2E–1	6.8E–1
			Average	**1.0E–4**	**1.2E–3**	**4E–5**	**5.1E–5**	**5.2E–4**	**1.1E–4**	**3.9E–4**	**1.1E–3**	**1.5E–3**	**1.6E–1**	**1.7E–1**
		ADIinh	Minimum	8.4E–12	2.0E–11	4.5E–13	2.7E–13	9.8E–12	3.7E–12	1.3E–11	1.9E–11	1.0E–11	2.5E–10	3.3E–10
			Maximum	1.4E–9	5.2E–8	1.6E–9	2.7E–9	1.5E–8	1.1E–9	2.3E–8	1.2E–7	3.1E–8	7.9E–7	1.0E–6
			Average	**1.6E–10**	**1.8E–9**	**6.1E–11**	**7.7E–11**	**7.8E–10**	**1.7E–10**	**5.8E–10**	**1.6E–9**	**2.3E–9**	**2.4E–7**	**2.5E–7**
		ADIderm	Minimum	2.4E–7	5.8E–7	1.3E–8	7.7E–9	2.8E–7	1.1E–7	3.6E–7	5.3E–7	2.9E–7	7.2E–6	9.6E–6
			Maximum	3.9E–5	1.5E–3	4.6E–5	7.7E–5	4.2E–4	3.1E–5	6.6E–4	3.3E–3	8.8E–4	2.3E–2	2.9E–2
			Average	**4.4E–6**	**5.3E–5**	**1.7E–6**	**2.2E–6**	**2.2E–5**	**4.8E–6**	**1.7E–5**	**4.6E–5**	**6.6E–5**	**7.0E–3**	**7.2E–3**

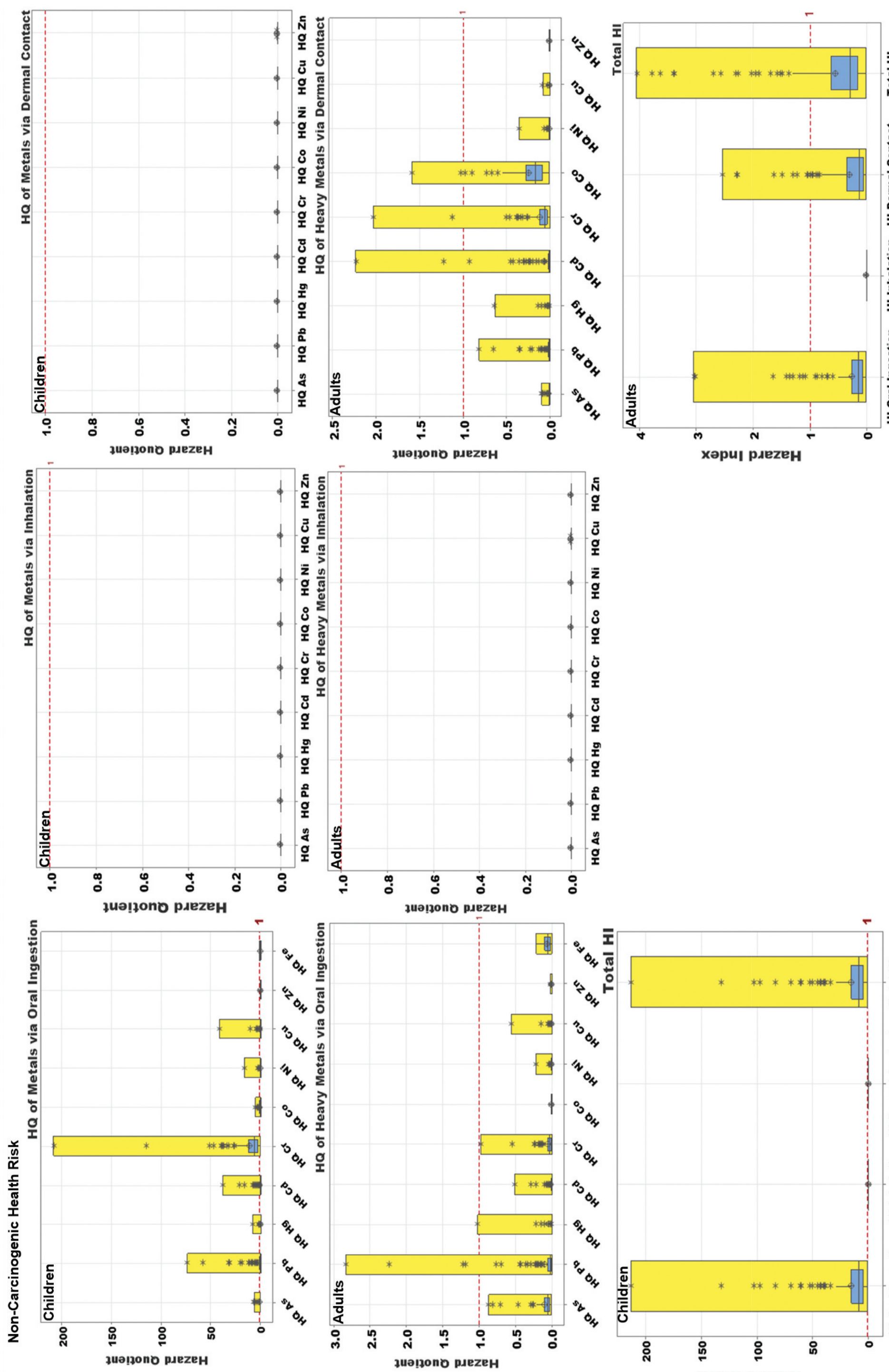

Figure 6. Hazard quotient (HQ) and hazard index (HI) for heavy metals' non-cancerous health hazards in urban soils.

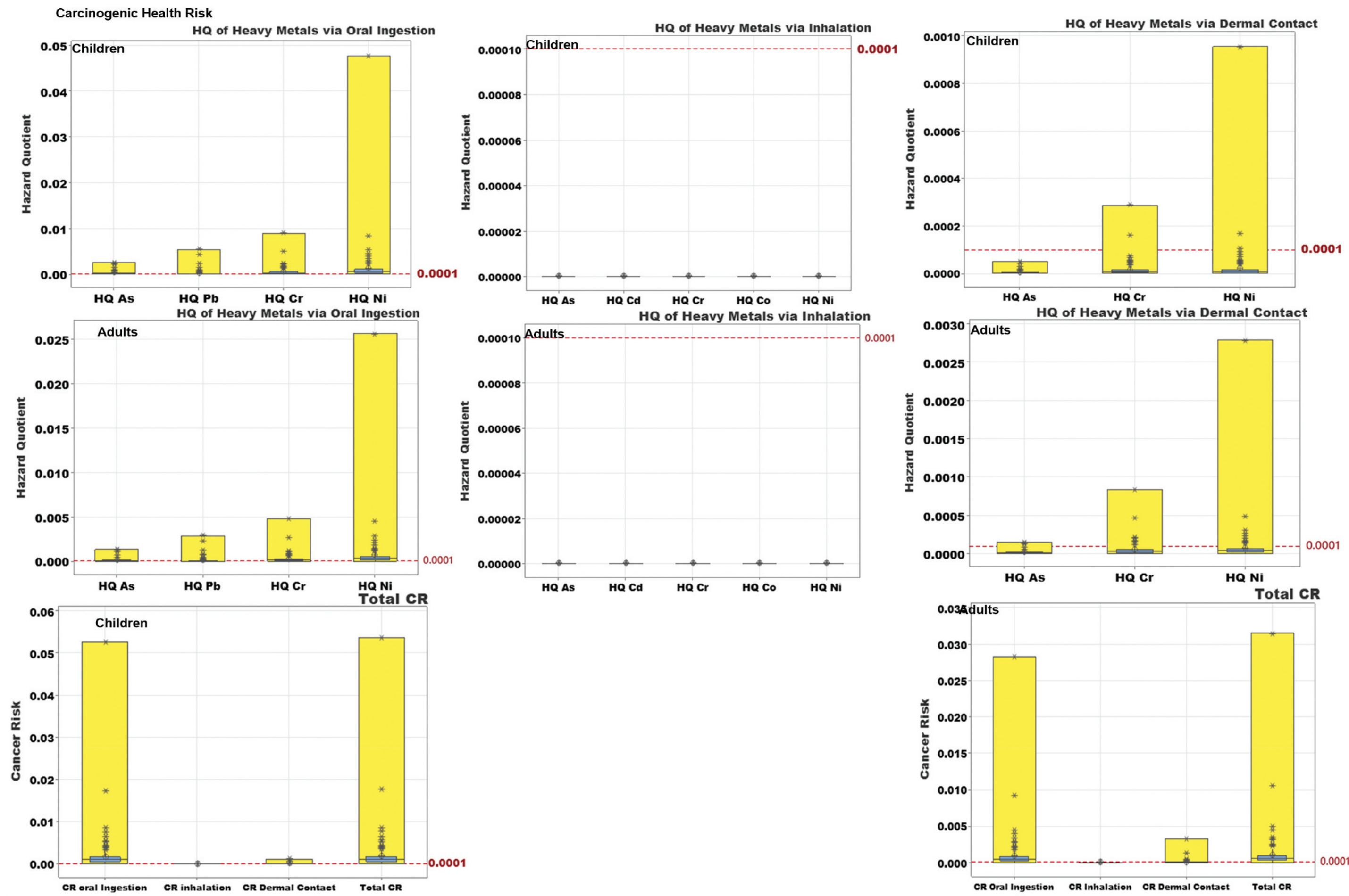

Figure 7. Hazard quotient (HQ) and hazard index (HI) for heavy metals' cancer health concerns in urban soil.

Moa, and Beishan have the highest HQ values for children's carcinogenic health concerns for As, Pb, Cr, and Ni. Kids exposed to Cr and Ni by skin contact in urban soils face carcinogenic health risks that are > 1E–4. In 178 cities, the overall cancer risk (TCR) for children is greater than 1E–4. This demonstrates that youngsters may be more susceptible to carcinogenic health concerns in 96% of the analyzed cities, which may be spread by oral consumption and skin contact with heavy metals (Figure 7). Similar to this, the HQ for adult carcinogenic health hazards from ingesting As, Pb, Cr, and Ni was > 1E–4. In urban soils, the HQ for As is > 1E–4 in 39 cities, whereas the HQ for Pb is greater in 29 cities. Additionally, HQ for Cr is greater in 102 city soils than 1E–4, but HQ for Ni is higher in 124 city soils. The soils of Arak, Kerman, Moa, and Beishan have the highest HQ values for the carcinogenic health concerns of As, Pb, Cr, and Ni for children. With the highest values observed in Arak, Moa, and Beishan, the HQ for carcinogenic health hazards for adults by dermal exposure to As, Cr, and Ni in urban soils was > 1E–4. In 46 places, the total cancer risk (TCR) for children is greater than 1E–4. This demonstrates that youngsters may be more susceptible to carcinogenic health concerns in 94% of the analyzed cities, which may be spread by oral consumption and skin contact with heavy metals (Figure 7).

Chronic obstructive pulmonary disease (COPD), peripheral neuropathy, cardiovascular disease, myocardial infarction, stroke, gout, lung cancer, and diabetes are just a few of the health problems that exposure to As can cause (Crinnion, 2017). Pb exposure over an extended period of time may result in high blood pressure, heart disease, renal disease, and decreased fertility (NIOSH, 2021). Pb may result in low birth weight, preterm delivery, and sluggish growth in neonates, while in adults it may cause memory loss, bipolar illness, aberrant sperm, low sperm count, miscarriage, and stillbirth in expectant mothers (Mayo Clinic, 2022). Mercury in the body can have deadly effects on the immunological, neurological, and digestive systems, as well as the lungs and kidneys (WHO, 2017). Cancer, osteoporosis, cardiovascular illnesses, and renal disease can all be brought on by cadmium (Fatima et al., 2019). Asthma and chronic bronchitis are two respiratory conditions that may be brought on by Cr in the body. The skin, kidney, liver, gastro-intestinal tract, heart, reduced red blood cell count, reproductive system, and cancer, particularly lung cancer, may also be impacted (ATSDR, 2013). Heart failure, polycythemia, and respiratory conditions like asthma can all be brought on by an excessive amount of Co in the body (Lauwerys & Lison, 1994). Ni may cause DNA damage, cancers such as lung cancer, immune system impairment, brain damage, cardiac issues, gastrointestinal disorders, difficulties with the muscles and skeleton, dermatitis, and an increase in blood glucose (Das et al., 2019). Humans who consume too much copper risk renal failure, heart failure, anemia, liver illness, brain damage, and even death (Eske, 2020).

4. Limitations and way forward

There are many small and medium-sized cities and metropolises around the globe; thus, the cities examined in this study might not accurately reflect the state of worldwide urban soil heavy metal contamination. This might be a result of the limited data from the soils of these cities. Also, the use of data from recent studies between 2010 and 2022 May have excluded results from some cities across the world. Additionally, there may be some disparities in the data gathered for heavy metal concentrations due to differences between researchers, which might affect how consistent the data is. Quantitative estimates of human risk also come with a number of inherent uncertainties. First, the USEPA exposure guide, which may not be appropriate for everyone on the globe, describes the exposure criteria. For non-dietary intake, cutaneous contact, and inhalation for both adults and children, there are often no published exposure recommendations. Second, our study did not account for the trace elements' bioaccessibility in the human gastrointestinal system. Instead, we took the conventional route and made the conservative assumption that the body absorbed 100 percent of the ingested trace elements. Finally, because there are now so few environmental studies available, a variety of additional developing metal pollutants (such as Barium, Vanadium, Strontium, thallium, etc.) should also be taken into consideration. The majority of this research concentrated on detection techniques and environmental contaminants' chemical forms. However, research on these novel pollutants is expanding quickly and should be taken into account in future surveys on soil heavy metal contamination.

5. Conclusions

Rapid expansion of cities have become the order of the day in many parts of the world especially in developing countries. This meta-analysis was carried out to unravel the extent of soil contamination in major cities across the world by heavy metals over a period of eleven years. For this study, information on heavy metals in soils from 174 cities worldwide was gathered through a systematic assessment of the literature in English-language databases. Despite its flaws, this research provided a worldwide overview of the pollution levels, health hazards, and ecological dangers associated with 10 heavy metals (As, Pb, Hg, Cd, Cr, Co, Ni, Cu, Zn, and Fe). Overall, the mean amount of As, Pb, Hg, Cd, Cr, Co, Ni, Cu, Zn, and Fe in major cities across the world are: 17.36 mg/kg, 206.97 mg/kg, 6.18 mg/kg, 8.68 mg/kg, 87.67 mg/kg, 18.59 mg/kg, 65.58 mg/kg, 179.35 mg/kg, 256.26 mg/kg and 27,401.01 mg/kg. Only the Cr and Fe concentrations were below the average crustal levels of the 10 elements examined in this study. The occurrence of maximum levels of As, Pb, Hg, Cd, Cr, Co, Ni, Cu, Zn, and Fe was found in the soils of Asak (Iran), Kerman (Iran), Lianyuan (China), Sagamu (Nigeria), Moa (Cuba), Al-Jubail (Saudi Arabia), Beishan (China), Bangkok (Thailand), Berlin (Germany), and Bangkok (Thailand), while the safest regions for these metals are Orlando (USA), Ras Tanura (Saudi Arabia), Lublin (Poland), Addis Ababa (Ethiopia)/Tshwane (South Africa), Taldykongam (Kazakhstan), Orlando (USA), Mumbai (India), Sadat (Egypt), Ras Tanura (Saudi Arabia), and Bogota (Colombo). According to the Geo-accumulation Index (Igeo), heavy metal contamination ranges from low to high in urban soils all over the world. According to the contamination factor, heavy metals contaminations range from extremely low to very high in urban soils all over the world. The Pollution Load Index (PLI) supported this claim. The study found that whereas both geogenic and anthropogenic activities have a substantial impact on the concentration of heavy metals in urban soils, human-related activities have a greater impact on their presence in the environment. These include activities such as increased industrialization, urbanization, geogenic sources, vehicular exhausts, industrial wastes, waste water, mining, waste management and agricultural activities are major contributors of heavy metals in soils of cities across the world. Heavy metals in urban soils were found to offer a low to high ecological danger, according to an ecological risk assessment. Human health risk assessment revealed that children living in 96% of the studied cities were found to be at risk for carcinogenic health risks, which can be triggered by oral ingestion and dermal contact with heavy metals, while they were also found to be susceptible to non-cancer-causing diseases through oral ingestion of soil-borne heavy metals. Adults in these cities have non-carcinogenic health hazards from oral Pb consumption and skin exposure to urban soil Cd, Cr, and Co. Ingestion of As, Pb, Cr, and Ni exposes them to adult health hazards that are carcinogenic. Therefore, regular monitoring of heavy metals in urban soils will not only expose the extent of contamination but also help in improving public and environmental health.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

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