Health risk assessment quantification from heavy metals contamination in the urban soil and urban surface deposited sediment

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ABSTRACT

Urban soil and urban surface deposited sediments (USDS) are a large basin for receiving heavy metal contaminants from natural resources and anthropogenic activities. The present study is a review carried out the previous studies determine metal impacts in the urban environment on potential health hazards. The environmental risk index (Eᵣ) values follow a trend for different urban soils and USDS: the high Eᵣ value in the period 1980–1990 in urban areas is due to Cd, followed by Pb, Cu, Zn, and Ni. The health risk assessment varied with the type of heavy metal, the time of year, the level of contamination, environmental pollution, and the human age. No significant risk was identified for adults and children in different urban areas.

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1. Introduction

Urban sediments are leaves, debris, and organic and inorganic materials present in the urban environment [1]. Urban sediments occur from natural sources; soil and rock weathering and atmospheric deposition [2–7], as well as anthropogenic sources; these include emissions from agriculture, municipal levels, road traffic, industrial and residential areas, and domestic emissions [8–11]. Sediments collect on various surfaces, such as roofs, roads, and driveways, during dry weather, in river bed and sewage systems, and in receiving reservoirs. Urban sediments can be divided into two categories – those that are deposited on surfaces and are primarily affected – air processes (urban surface deposited sediments, USDS), besides of deposits in the aquatic environment [12,13].

In recent years, sediment deposition in urban areas has received considerable attention due to the ease of sampling sediment material and its ability to act as an indicator of urban pollution levels [13,14]. USDS are particles consisting of sediments, soil, leaves, debris, and organic and inorganic materials [12,15]. They do not stay long in one place, but rather are suspended in atmospheric particles containing metal concentrations or precipitation washes plus solid urban roads and catchments dissolved [16,17]. Consequently, it is important to focus on the contamination in urban soil and USDS simply due to the amount of heavy metal accumulated in the soil and USDS that it depends on the geological origin, soil texture, chemical and physical properties of the urban soil and USDS [20–23]. USDS reduce the quality of the environment and contribute to the perception of an unfavourable urban environment. Moreover, high levels of heavy metals in urban areas are a sign of rapid urbanization of our environment due to population growth and land use [24,25]. Furthermore, development in an urban environment can affect human health [26]. One of the three major mechanisms, ingestion, inhalation, and dermal contact, induced toxic health effects in the body [26–30]. In the urban environment, atmospheric deposition plays a role, where, USDS contains small particulate matter (PM), including PM2.5 and PM10 fractions, which poses a significant health risk [31].

Therefore, to help mitigate heavy metal exposure strategies, the main purpose of the present review was to provide background data to legislators, developers, and governments to understand better the effect of land use patterns on pollution hotspots and the health risks of soil metals and USDS. The objectives were to (1) assess the distribution of metals in the soil and USDS in the world, (2) Evaluate land use effect on metal distribution, (3) assess potential indicators, the potential environmental risk index (Eᵣ) and the environmental risk index (RI) imposed by the assessment of the risk for heavy metals and the health impact that metals in the soil and USDS represent.

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2. Materials and methods

This study provides an overview of the worldwide risk assessment of heavy metal in the urban environment. The analysis covers 2,776 samples collected from various urban landscapes. The analysis of heavy metal concentrations in urban soil and USDS was compiled throughout the period 1979–2018 from various online articles databases such as Web of Science, Science Direct, Scopus and Google Scholar publications. The quote system followed paper after paper with a link through end-to-end links. Various analytical methods used by researchers for the digestion of heavy metals. The urban samples were collected regularly and randomly from urban surfaces used in sweeping tools such as brush or a plastic scoop, and then transferred to the laboratory through a plastic bag before drying at various temperatures. To determine the concentration of heavy metal in the collected samples, various acids such as HNO\textsubscript{3}, HClO\textsubscript{4}, H\textsubscript{2}SO\textsubscript{4}, H\textsubscript{2}O\textsubscript{2}, and H\textsubscript{3}BO\textsubscript{3} used for digesting process shown in Figure 1. From Figure 1, the most common method used for digesting is HNO\textsubscript{3} + HCl and HNO\textsubscript{3} + HF + HClO\textsubscript{4}.

Heavy metal in the collected samples from various landscapes areas were analyzed using different analytical approaches, such as inductively coupled plasma (ICP), atomic absorption spectroscopy (AAS), Instrumental neutron activation analysis (INAA) and X ray fluorene (XRF). The analytical methods distribution is shown in Figure 2. From Figure 2, AAS is the most analytical method used to determine the concentrations of heavy metal. This is because it considers a destructive technique, but it does have good reliability and accuracy. Recently, various types of ICP have been developed and widely used.

Figure 1. Various acids used in the digestion process.

Figure 2. The distribution of analytical techniques.

2.1. Heavy metal risk assessment

2.1.1. Potential ecological risk index

In urban soil and USDS, the toxicity and ecological hazards posed by heavy metal suggested by ZHU et al. [32] and first reported by Hakanson [33]. According to this methodology the potential risk of individual metal element can be determined as follows:

$$E_i = C_i \times T_i = \left( \frac{C_i}{C_{ir}} \right) \times T_i$$  \hspace{1cm} (1)

where, $T_i$ is the toxic-response factor for a single heavy metal contamination was taken as, 1 for Zn, 5 for Cu, Pb and Co, 10 for As and 30 for Cd [34,35]. $C_i$ is an index for contamination of a given heavy metal, $C_i$ is the present concentration of heavy metal in the urban soil and USDS and $C_{ir}$ is the reference value of heavy metal in the urban soil. The references values of the average shale in the urban environment used in this work are from Fadigas et al. [36]. These values are: Cu 35.1, Cd 0.5, Pb 17, Zn 59.9 and Ni 13.2 mg kg\textsuperscript{-1}. The sum of potentially individual risks ($E_i$) is the potential ecological risk index (RI) can be
AF is the skin adherence factor for soil (mg/cm²-day), using Equations (3–5):

The potential ecological hazard and the risk criteria as resulted in heavy metal accumulation in the urban soil and USD$S are classified into risk categories given in Table 1.

### 2.1.2. Health risk assessment

In the urban environment, three main pathways of human exposure to heavy metal. These pathways are: via various pathways [39–41]: (1) ingestion ($D_{inh}$); (2) inhalation ($D_{inh}$); and (3) dermal contact [37,38]. The health risks via the main pathways can be detected using Equations (3–5):

$$D_{inh} = \frac{C \times R_{inh} \times ED \times EF}{AT \times BW} \times 10^{-6}$$  \hspace{1cm} (3)$$

$$D_{inh} = \frac{C \times R_{inh} \times ED \times EF}{AT \times BW \times PEF} \times 10^{-6}$$  \hspace{1cm} (4)$$

$$D_{dermal} = \frac{C \times AF \times SA \times ED \times EF \times ABS}{AT \times BW} \times 10^{-6}$$  \hspace{1cm} (5)$$

where, $C$ is the concentration of heavy metal (mg/kg), $R_{inh}$ is the ingestion rate (mg/day), $ED$ is the exposure frequency (days/year), $AT$ is the averaging time, $BW$ is the average body weight (kg), (days), $R_{inh}$ is the inhalation rate (mg/cm²), $PEF$ is the particle emission factor (m³/kg), $AF$ is the skin adherence factor for soil (mg/cm²-day), $SA$ is the surface area of the exposed skin that is in contact with the sample (cm²), and $ABS$ is the dermal absorption factor (unitless). Exposure factors used in the non-Carcinogenic Risk $D_{dermal}$ estimate given in Table 2.

### 2.1.3. Non-carcinogenic risk assessment

The concentrations of heavy metal were applied to assess the adult and children’s health risks both carcinogenic and non-carcinogenic. Hazard quotient (HQ) calculated to determine non-carcinogenic health risk for each individual heavy metal element as described in Equation (6) [39]:

$$HQ = \frac{D}{RFD}$$  \hspace{1cm} (6)$$

where, $RFD$ Where, $RFD$ reflects the chronic reference dose for each heavy metal (mg/kg-day) as given in Table 3 [43].

A risk index (HI) has been developed to measure the risk of carcinogenic health effects pose by heavy metal. HI HI is the sum of three major pathways’ hazard quotient as shown in Equation (7) [42]:

$$HI = \sum HQ = HQ_{ inh} + HQ_{ inh} + HQ_{ derma}$$  \hspace{1cm} (7)$$

The values of HI are classified into two categories. When HI < 1 is no harmful effect to the health, while HI > 1 There is no potential for adverse effects on health.

### 2.1.4. Carcinogenic risk assessment

The life time cancer risk (LCR) was estimated to determine the health risk for carcinogenic heavy metal by calculating the cumulative life cancer risk rating using Equation (8) for each exposure pathway:

$$LCR = D \times SF = \sum cancer risk = cancer risk_{ inh} + cancer risk_{ inh} + cancer risk_{ derma}$$  \hspace{1cm} (8)$$

Where, SF is the slope factor for carcinogenicity (by mg/kg-day) was presented by USEPA, 2012 for the related heavy metal Cd, Pb are 6.3, and, 0.0085 mg/kg/day [43]. In overall, the acceptable threshold value of LCR $1 \times 10^{-4}$ is considered to have significant health effects LCR of $1 \times 10^{-6} – 1 \times 10^{-4}$ is widely considered acceptable, and LCR below $1 \times 10^{-6}$ is regarded as negligible [44].
Table 4. Concentrations of heavy metal (mg kg$^{-1}$) in urban soils and USDS in the different cities around the world.

| City                   | Country       | Cu  | Pb  | Zn  | Ni  | Cd  | References |
|------------------------|---------------|-----|-----|-----|-----|-----|------------|
| Lancaster              | UK            | 143 | 1880| 534 | 35  | 4.6 | [49]       |
| Scotland               | Great Britain | NC  | 756 | 422 | NC  | NC  | [50]       |
| Lancaster              | England       | 19.9| 20  | 20.2| NC  | 20  | [51]       |
| Various sites          | Hong-Kong     | 91.5| 1556| 2377| 14.5|     | [52]       |
| New York               | USA           | 356 | 2583| 1811| NC  | 8   | [53]       |
| Various sites          | Nigeria       | 12  | 111 | 31  | 1.9 | 0.7 | [54]       |
| Halkyn, North Wales    | Great Britain | 200 | 480 | 1166| NC  | 0.8 | [55]       |
| Athens                 | Greece        | NC  | 121 | 125 | 128.45| 2.4 | [20]       |
| London                 | UK            | NC  | 1030| 680 | NC  | 3.5 | [56]       |
| Kuala Lumpur           | Malaysia      | NC  | 2466| 344 | NC  | 3   | [57]       |
| Cuenca                 | Equador       | NC  | 108 | 218 | NC  | 0.33| [58]       |
| London                 | England       | 73  | 294 | 183 | NC  | 1   | [24]       |
| Various sites          | Bahrain       | NC  | 697 | 152 | 126 | 7   | [59]       |
| Various areas          | Bahrain       | NC  | 742 | 67  | 12  | 1.5 | [60]       |
| Seoul                  | Korea         | 101 | 2582.5| 1811| NC  | 3   | [61]       |
| Sault Ste Marie        | Canada        | 87.3| 90.5| 227 | 26.5| 0.85| [62]       |
| Oslo                   | Norway        | 123 | 182 | 412 | 41  | 1.4 | [63]       |
| Taejon                 | Korea         | 57  | 52  | 214 | NC  | NC  | [64]       |
| California Bight       | USA           | 15  | 10.9| 59  | 18.1| 0.33| [65]       |
| Seoul                  | Korea         | 269 | 144 | 532 | NC  | NC  | [51]       |
| Kowloon Peninsular     | Hong Kong     | 24.8| 93.4| 168 | NC  | 2.8 | [25]       |
| Bursa                  | Turkey        | NC  | 210 | 57  | NC  | 3.1 | [67]       |
| Istanboul              | Turkey        | 152 | 184 | 477 | 30.36| 2.11| [16]       |
| Birmingham             | UK            | 466.9| 48 | 534 | 41.1| 1.62| [68]       |
| Karak                  | Jordan        | 11.3| 11.2| 13.1| 4.2 | NC  | [69]       |
| Luanda                 | Angola        | 42  | 315 | 317 | 10  | 1.1 | [17]       |
| Kayseri                | Turkey        | 36.9| 74.8| 112 | 44.9| 2.53| [70]       |
| Amman                  | Jordan        | 243 | 737 | 293 | 67  | 6.9 | [71]       |
| Urumqi                 | China         | 94.54| 53.53| 294.47| 43.28| 1.17| [72]       |
| Hangzhou               | China         | 116.04| 202.16| 321.4| 25.88| 1.59| [19]       |
| Baqii                  | China         | 123.17| 408.41| 715.1| 48.83| NC  | [73]       |
| Kavala                 | Greece        | 124 | 301 | 272 | 58  | 0.2 | [74]       |
| Delta                  | Egypt         | 102 | 308 | 1840| 38.5| 2.98| [75]       |
| Ulsan                  | Korea         | 148 | 118 | NC  | 38.5| 1.5 | [76]       |
| Intertidal Bohai Bay   | China         | 24  | 25.6| 73  | 28  | 0.12| [77]       |
| Murree                 | Pakistan      | 156.9| 145.8| 890 | 47.8| 8.4 | [78]       |
| Gorimedium             | India         | 202.24| 156.63| 222.46| NC  | 6.54| [79]       |
| Intertidal Laizhou Bay | China         | 10.99| 13.37| 50.63| 17.38| 0.19| [80]       |
| Intertidal Jiaozhou Bay| China         | 38.8 | 55.2| 107.4| NC  | 0.4 | [81]       |
| Tijuana                | Mexico        | 50.2 | 31.8| NC  | 0.1 | [1]  |
| Jiaozhou Bay           | China         | 27.31| 38.54| 76  | 32.35| 0.304| [18]       |
| Villavicencio          | Colombia      | 126.3| 87.5| 133.3| 5.3 | NC  | [27]       |
| Villavicencio          | Colombia      | 47.7 | 20.7| 118.1| 1.3 | 0.04| [82]       |
| Ekerenburg SnDS        | Russia        | 105 | 103 | 455 |     |     | [83]       |
| Nizhnyi Novgorod USDS  | Russia        | 33  | 21  | 147 |     |     | [10,14]   |

Note: NC: Not counted.

3. Data analysis

Contamination of heavy metal is becoming more common in the world because of the economic and population development. Numerous studies indicate ranges the concentration of heavy metal observed in urban soil and USDS in particles consisting of leaves, debris, and organic and inorganic materials [1,13,45]. The concentration of heavy metal Cu, Pb, Zn, Ni and Cd in urban soil and USDS are shown in Table 4 and Figure 3.

3.1. Heavy metal concentrations in urban soils and USDS

Table 4, shows Cu, Pb, Zn, Ni, and Cd concentrations in urban soils and USDS in different cities around the world based on collected published data obtained from another studies. It results in varying the concentrations of heavy metal in urban soil and in USDS (Figure 3), where few cities have higher concentrations of heavy metals than others [36]. Moreover, the highest Cu pattern values between the outer and inner ring roads were found in Birmingham, UK, [46]. As a consequence, Cu will occur due to mechanical vehicle abrasion and high-value position in Birmingham. However, vehicle emissions, Kuala Lumpur (Malaysia) with the highest Pb concentrations, followed by New York (USA) and Seoul (Korea) are the main source of Pb on urban soil and USDS. However, with reference, the annual change in Pb is decreasing, despite an increase in traffic volume due to non-use of lead fuel. Furthermore, Zn's origins on urban soil and USDS are metal parts of vehicles and exhaust gases from automobiles. Additionally, there is a wide range to the annual spread of Zn concentrations. automobile emissions in Athens (Greece) and various locations in Bahrain, however, are the most important of Ni concentration. Thus, with subsequent years, the annual increase in concentration of Nickel decreases.
Figure 3. Boxplots of the concentrations of heavy metal (mg/kg) for the sampling sites examined in the urban regions of the various cities around the world.

High levels of Cd in USDS in various places in Bahrain are the product of household dust, which may be due to the abrasion of the rubber corrosion on carpets [47,48], as well as a fragment of car tires. In general, heavy metal contamination is based on anthropogenic land use sources and rapid urbanization, while traffic and population are important factors.

3.2. Environmental ecological risk assessment

The distribution of the possible ecological risk index for heavy metals from 1979 to 2018 over the last decades is shown in Figure 4. \( E_r \) values follow the trend for different urban soils and USDS: according to Table 1 and Figure 4, \( E_r \) is divided into two main categories, low and moderate, while the second is high and very high in the years studied. It is evident that in the various cities surveyed during the years studied, RI has a significant trend in urban soil and USDS. It has been found that high and very high-risk accounts for 90% of total environmental risk in the 1980–1990 period, which was the highest ecological risk measured in all urban areas. This indicated a high potential \( E_r \) risk in urban areas due to Cd 7200, followed by Pb 662, Cu 42, Zn 23, and Ni 6. At the same time, the low and moderate risk is zero for the same duration.
Figure 4. Ecological risk assessment of heavy metal in urban soil and USDS over the decades (share of cities assigned to low, moderate, high and very high categories by ER).

3.3. Health risk assessment

Several studies have documented the threats to public health associated with different sediment types. This study demonstrates elevated and potentially carcinogenic concentrations of heavy metals in urban sediments. The assessment of health risk differed depending on the type of heavy metal, time of year, emission level, toxicity of the atmosphere and human age [84]. The assessment of human health risk from urban sediments for adults and children for three main exposure routes is estimated and reported in Tables S1 and S2. The ingestion of urban soil and USDS particles was established as the main route for non-carcinogenic risk through exposure to heavy metal in adults and children, with subsequent skin contact [17,82,85,86]. For general, as shown in Tables S1 and S2, all adults and children have healthy because the values of HI (< 1), with the exception of two Eastern American metropolitan areas (USA and Canada). Nevertheless, the HI levels were higher for children than for adults. Lower body weight and higher ingestion levels in children can be linked to higher ingestion and skin contact risk values, respectively [87]. However, encouraging good hygienic practices is advised to reduce the potential risk to children. To prevent the health risks associated with USDS exposure in adults, both shortening outdoor time and wearing appropriate masks could have an impact [87]. The average HI values for these metals for an individual fall in the following order: Pb > Cd > Cu > Zn > Ni. The LCR values for the three main paths appearing in Figure 5.

Figure 5. LCR values of Pb and Cd for three main pathways both adult and child was attributed from the urban soil and USDS.
resulted from Pb and Cd. In most urban areas, except for certain urban areas that exceeded this value, the LCR was below the threshold value (1E-06–10-04E). Nevertheless, it is important to pay attention to possible health risks due to exposure in areas with higher metal concentrations, especially for children, cleaners, public transport drivers and residents of the region.

4. Conclusion

Cities around the world vary in population, growth, and rapid urbanization. In the urban environment, there are various sources of heavy metal. The intensity of use of these heavy metals and their distribution depend on the properties of each city. Furthermore, the result also indicates Cu, Pb, Zn, and Cd concentrations in the urban soil and USDS are mostly originated from anthropogenic sources. However, the geogenic sources is mostly origin of Ni. Thus, the highest concentrations of heavy metal in the urban environment were affected population, industrial activity, and traffic. While, the places with low traffic and a small population have the lowest concentrations. As clarified that the modern cities development, as well as rapid urbanization, are the main causes of heavy metal contamination in the urban soil and USDS. An ecological risk assessment in an urban environment is a high and very high risk, which accounts for 90% of the total environmental risk in the period 1980–1990. Moreover, the health risk assessment influenced by various factors such as on the type of heavy metal, the time of year, the level of pollution, and the human age. Finally, no significant risk was contributed for adults and children in the urban environment.

Disclosure statement

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

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