Heavy metal levels of outdoor dust from the Eastern Mediterranean Sea region and assessment of the ecological and health risk

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Abstract

As a result of some chemical elements (heavy metals) pollution of dust, the environmental concern of environmental pollution of dust has become an increasing concern, necessitating an assessment of risks to both ecology and human health, particularly in urban areas. The majority of these pollutants settles on the outdoor and eventually become part of the outdoor dust. These will have negative long-term repercussions on ecosystems and human health. In this research, energy dispersive X-ray fluorescence (EDXRF) spectrometry analytical method was used to assess the pollution characteristics of the eight heavy metals (HMs): Mn, Cu, As, Hg, Ni, Cr, Zn, and Pb in the East Mediterranean Sea area. The concentration of As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn analyzed in outdoor dust samples varied from 0.94 to 19.52 mg kg^{-1}, 190.08 to 1019.7 mg kg^{-1}, 20.46 to 45.9 mg kg^{-1}, 19.5 to 62.56 mg kg^{-1}, 0.01 to 0.93 mg kg^{-1}, 10.48 to 40.64 mg kg^{-1}, 12. 6 to 36.1 mg kg^{-1}, and 48.96 to 112.41mg kg^{-1}, respectively. HMs have been detected in the outdoor dust samples analyzed in the study and, as a result, mean concentrations followed the order Mn>Zn>Cu>Cr>Ni>Pb>As>Hg, respectively. The ecological risk was observed at various contamination levels, with As and Hg pollution being the most severe. The highest hazard quotient (HQ) for adults and children was determined as a result of As and Cr, respectively. According to the US-EPA health risk threshold, the risk of cancer risk in study area is negligible.

Keywords: Outdoor dust, Metal pollution, Human health, Ecological risk, Cyprus

1- Introduction

Some chemical elements, called heavy metals (HMs) in this manuscript are the main toxic elements in atmospheric dust pollution, and due to their high toxicity, inability to dissolve, and persistence, they pose a risk to both human health and the environment (Li et al. 2022; Sultan et al. 2022). All terrestrial ecosystems contain natural components of the Earth's crust, including these elements, as well as anthropogenic elements from industrial activity and mining. As their concentration in natural ecosystems has changed over the past decades, however, this research tried to understand their adverse effects (Abbasi and Mirekhtiary 2020a).

There are many different sources of HMs in urban soils and outdoor dust, including products of industrial processes, agricultural production, and other human activities (household trash, transportation, building, mining, etc.) (Wu et al. 2022). Due to this property of these materials, they are able to make into direct contact with the mouths and hands of humans infiltrate agricultural or aquaculture products. Subsequently, there is a potential for indirect eaten by humans, which poses a threat to human health (Pandion et al. 2022). Regarding to prior research, intemperate heavy metals in the human body have a negative impact on organs, immunological systems, endocrine systems, skin damage, skin cancer, peripheral neuropathy, vascular disease, and endocrine enzyme damage (Barchielli et al. 2022; Goyal et al. 2022; Nivetha et al. 2022).

It is believed that the higher the heavy metals, the more they are produced as they are the result of the traffic emissions, land development, and industrial activities which surround all those urban resources. Depending on the levels of pollutants in the air in different cities, pollution levels vary quite a bit by the human activities (for example, industrial activity, traffic, etc.) and technologies used, as well as the local weather and wind conditions (Wang 2016).

Outdoor HMs and particles eventually deposit on land via wet and dry deposition processes, resulting in pollution buildup(Altaf et al. 2021). Moreover, HMs deposited on the ground might be washed away by rainwater runoff, contributing to the total contamination of recipient aquatic bodies (Weerasundara et al. 2017; Vithanage et al. 2022).

Non-essential and essential metals in the human body are typically classified as non-essential metals and essential metals, respectively. Terms of essential metals, like manganese and chromium are essential in body metabolism, while non-essential metals are those such as arsenic, mercury, and lead, which are non-essential (Jiang et al. 2020). For the proper functioning of living beings, essential metals are essential for maintaining a stable level of health and wellness. Deficiencies or harmful effects are induced on living beings when essential metals are reduced or overtaken over their required range. Metals that are not essential in small quantities are toxic and pose a significant health risk to individuals who are exposed to them (Abbasi et al. 2022a).

The damage caused by heavy metals in the environment on the general population is not directly observable in the same way as diseases, but many of the effects that may result from an increase in heavy metal pollution are subclinical and therefore undetected, but they are not as visible as disease does. It may be that some of these effects are latent and will be detected later on after the toxic stress has abated. Furthermore, the effects of heavy metals are determined by the concentrations of the metals reaching the individual, which cannot be predicted because of stochastic variables such as weather conditions and distance from the source of the metals. Because of these stochastic factors, the number of occurrences of a particular effect cannot be measured directly. Since these stochastic factors cannot be directly measured, it's impossible to determine how often a particular effect occurs (Krenkel 2013).

Several studies have demonstrated that HMs may be harmful to both natural systems and human health (Abbasi and Mirekhtiary 2020b; Roy et al. 2022; Wang et al. 2022; Zhou et al. 2022; Ajayi et al. 2023). The purpose of this research referred to evaluate the concern of heavy metals Arsenic (As), Manganese (Mn), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), and Zinc (Zn) in outdoor dust of the Eastern Mediterranean Sea region, and assessed the risk in the study area. For this purpose, the HMs concentration, pollution index, and Health risks (noncarcinogenic and carcinogenic risks) were calculated in the study area.

The novelty and purpose of this literature for the readers is to present the concentration of heavy metals in outdoor dust on the island of Cyprus which is surrounded by water. The importance of this issue is because of the origin of this pollution that reaches this island from across the waters.

2. Materials and methods

2.1. Study area

The north area of Cyprus is located between latitude 35° 10' 17.6275" and 35° 42' 6.9002" N and longitude 32° 42' 58.6763" and 34° 36' 37.5529" E, West of Syria and south of Turkey. Cyprus is the third largest island in the Mediterranean after Sicily and Sardinia. The greatest dimensions of this island are 220 km in length and 90 km in breadth. The area of Cyprus Island is roughly 9251 km^2. The study area was selected from the northern section of Cyprus. There is an old copper mine in the study area. The mining started in the western coastal region in 1914 because of the ancient Roman slag piles that were rich in copper, and the firm was founded in 1916. The mine left behind tons of tailing deposits that were left exposed to the environment when the mining operation was abandoned in 1974 (Abbasi et al. 2022b).

Fig 1. Sampling sites in the Eastern Mediterranean Sea region based on their geographical location

2.2 Collecting and preparing the samples

A total of 54 outdoor dust samples from 19 sampling sites (each weighing over 100 g) were collected from various places in the fall season of North Cyprus that were identified as highly populated distribution districts (Fig. 1). The samples were collected from the untouched places that indicate the settling of dust from the air. These places included the edge of some buildings and some parked cars. At each sample site, a dirt-free polymeric dustpan and brushes were utilized, and sampling was done carefully to limit the disruption of small particles. As described in the literature, our sampling preparation procedure is very similar to the one that has been used in previous studies (Abbasi et al. 2022a). The samples were delivered to the laboratory in self-sealed polyethylene containers. Initially, materials such as small fragments of brick, paving stone, leaves, and other waste were removed. The samples were then dried in an oven at 105 °C for 48 hours before being mechanically sieved. The grain size of the sample was 65 µm when sieved. Subsamples were weighed and stored in polyethylene container in a dry area until analysis. There were a variety of particles that were selected for this fraction, including those of 65 micrometers in diameter, since these particles can be efficiently carried in suspension and the finest particles can remain outdoor for an extended period (Shilton et al. 2005). Additionally, fine particles are typically connected with higher health concerns than coarser particles.

2.3 Heavy metals (HMs) analysis

Energy-dispersive-X-ray-fluorescence (EDXRF) spectrometry (Spectro Xepos) system was used to analyze the HMs in the dust samples, and an X-ray tube was used (work power:50 W & energy bond:60 kV). A band pass filter on the EDXRF spectrometer is designed to increase the performance of the detector in the K-Mn range, while a highly annealed pyrolytic graphite polarizer is designed to enhance the sensitivity to Na-Cl elements. The EDXRF spectrometer uses polarization and secondary targets to enhance the excitation. It features software modules and an autosampler that can sample up to 12 things. The target changer, which can accommodate up to eight secondary targets with polarization, provides a wide range of excitation conditions to provide the best determination of all components from K to U. The details of the analysis procedure have been explained in the previous report(Abbasi et al. 2022a).

The sophisticated calibration methods used by the EDXRF spectrometer, such as "standard" calibration, which is often based on the fundamental parameters (FP) approach, are used. The EDXRF measurements were carried out by using soil reference elements (NIST-SRM-2709) (Mackey et al. 2010) to ensure the system's quality control. The sample cups that had been prepared for each soil sample were put into the automated sampler, and the analytical operations were finished by counting them once every two hours. The analytical process's total level of uncertainty ranges from 5 to 15%. The detection limits for Zn, Pb, Ni, Hg, Cu, and Cr were found in order of 0.5, 0.8, 0.5, 1, 0.5, and 1 mg kg^{-1}, respectively.

2.4 Determination of pollution index

It is known as the pollution index (PI) which represents the ratio between the metal content of outdoor dust and the reference material. The developed model by (Hakanson 1980) was used and presented by Eq.(1). To assess the level of heavy metal pollution at each sampling site, PI values were calculated. Hakanson's (1980) model divides contamination levels into four categories: PI > 6, very high; 3<PI<6, high; 1<PI<3, moderate; and PI<1, low risk (Hakanson 1980). Moreover, Tomlinson et al. (1980) established the pollutant load index (PLI) model to assess contamination levels between various sample sites(Tomlinson et al. 1980). The PI values were calculated in Eq. (1), and the PLI values were obtained in Eq. (2):

$$\boldsymbol{PI = \frac{C_n}{C_b}} \quad (1)$$

$$\boldsymbol{PLI = (PI_1 \times PI_2 \times PI_{13} \times \ldots \times PI_n)^{\frac{1}{n}}} \quad (2)$$

There are three elements to this equation: PI represents the pollution index single factor for each metal, C_n represents the level of that metal in the dust sample and C_b represents the background level of that metal (mg/kg). Insignificant contamination: PI< 1, Moderate contamination:1–3, Considerable contamination: 3–6 and High contamination: > 6 (Aguilera et al. 2021). Based on the PI value of the dust quality, it could be categorised into three levels, namely low pollution level (PLI ≤ 1), moderate pollution level (1 ≤ PLI ≤ 3), and high pollution level (PLI ≥ 3) (Wan et al. 2016; Gupta et al. 2022) that in this research were called Category A, Category B, and Category C, respectively.

2.5 Health risks assessment

The Environmental Protection Agency (Staff 2001)has developed a model that identifies the health risks associated with inhaling, touching, ingestion, and skin contact with heavy metals in outdoor dusts. This model was used to evaluate the health risks. Carcinogenic and non-carcinogenic risks can be categorized into two categories according to the degree of health risk.

2.5.1 The noncarcinogenic effects

The noncarcinogenic health risk was evaluated as a function of daily dose and computed independently for each trace metal and exposure pathway by Eqs. (3)– (5).

$$\boldsymbol{ADD_{inh} = \frac{C_{dust} \times R_{Inh} \times EF \times ED}{AT_{nonca} \times BW \times PEF}} \quad (3)$$

$$\boldsymbol{ADD_{der} = \frac{C_{dust} \times SA \times AF \times ABS \times CF \times EF \times ED}{AT_{nonca} \times BW}} \quad (4)$$

$$\boldsymbol{ADD_{ing} = \frac{C_{dust} \times R_{Ing} \times EF \times ED \times CF}{AT_{nonca} \times BW \times AT_{car}}} \quad (5)$$

In the following formula, $\boldsymbol{ADD_{inh}}$ is a daily dose representing the average dose caused by inhalation exposure (mg kg^{-1} day^{-1}), and $\boldsymbol{ADD_{der}}$ is daily dose representing the average dose caused by dermal contact exposure (mg kg^{-1} day^{-1}), as well as $\boldsymbol{ADD_{ing}}$ is daily dose representing ingestion exposure (mg kg^{-1} day^{-1}).The other parameters with references were presented in Table 1.

The hazard index (HI) and hazard quotient (HQ) are two parameters that used for noncancer risk calculation. In the following Eqs (6) and (7) were used to determine the HQ and HI values:

$$HQ = \frac{ADD_{inh+der+ing}}{RfD} \quad (6)$$

$$HI = \sum HQ_{inh+der+ing} \qquad (7)$$

In this case, RfD is an approximated value that determines the level of risk associated with exposure to a particular element every day for the remainder of a human's life that can cause the greatest harm to the population. It is currently recommended to use three different types of reference doses (RfD) to correspond to three different types of exposure pathways: reference dose RfD_o (mg kg^{-1} day^{-1}) for ingestion, RfD_{ABS} (mg kg^{-1} day^{-1}) for dermal contact and RfD_i (mg m^{-3}) for inhalation exposure. (USEPA 2013; Yadav et al. 2019).

2.5.2 The carcinogenic effects

The results for the lifetime average daily dose are based on skin contact, ingestion, and inhalation exposure. To assess the carcinogenic effect of exposure to outdoor dust polluted with heavy metals, the incremental lifetime cancer risk (ILTCR) was estimated. There are several ways in which the additional lifetime risk of cancer induced by exposure to a carcinogen can be quantified by studying the probability of developing cancer as a result of such exposure. EPA recommends that typically tolerable cancer risks fall between $1x10^{-6}$ and $1x10^{-4}$, based on its experience with cancer risk (Means 1989). There is a combination of the lifetime average daily dose ($LADD_{inh}$), the cancer slope factor (CSF_{inh}), and ILTCR that is determined using the following equations to estimate the incremental lifetime cancer risk (ILTCR) caused by inhalation:

$$LADD_{inh} = \frac{C_{dust} \times R_{Inh} \times EF \times ED}{AT_{ca} \times BW \times PEF} \qquad (8)$$

$$\boldsymbol{LADD_{der} = \frac{C_{dust} \times SA \times AF \times ABS \times CF \times EF \times ED}{AT_{ca} \times BW}} \qquad (9)$$

$$\boldsymbol{LADD_{ing} = \frac{C_{dust} \times R_{Ing} \times EF \times ED \times CF}{AT_{ca} \times BW \times AT_{car}}} \qquad (10)$$

$$ILTCR = LADD_{inh} \times \mathrm{CSF}_{inh} \qquad (11)$$

where, $\boldsymbol{LADD_{inh}}$, $\boldsymbol{LADD_{der}}$ and $\boldsymbol{LADD_{ing}}$ are lifetime average daily doses of inhalation, dermal, and ingestion, respectively. $\boldsymbol{ILTCR}$ is incremental lifetime cancer risk caused by inhalation exposure. The other parameters with references were presented in Table 1.

Table 1. Variables and parameters of exposure applied in risk assessment calculation.

2.6 Statistical analysis

The HM's data were analyzed with the aid of Minitab® (Ver. 19) software, which was used to calculate statistical parameters (Min, Max, Mean, Kurtosis, Skewness) of the data. To investigate the sources of HMs in the dust, Pearson's correlation was applied, as well as principal component analysis (PCA) was employed. Using Varimax rotations as the means of calculating factors and clusters, we were able to perform factor analysis (FA, the components of the PCA). In order to clarify the PCA results, a rotation such as Varimax was used since orthogonal rotation minimizes the number of factors with high loading on each component and thereby facilitates elucidation of the results.

3. Results and discussion

3.1 Heavy metals concentration in outdoor dust

The concentrations of potentially harmful metals in the study area outdoor dust were presented in Table 2. The mean concentrations of As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn in outdoor dust were 7.66 mg kg^{-1}, 568.79 mg kg^{-1}, 30.25 mg kg^{-1}, 46.76 mg kg^{-1}, 1.59 mg kg^{-1}, 22.93 mg kg^{-1}, 22.36 mg kg^{-1}, and 87.94 mg kg^{-1}, respectively. This table also includes the Earth's crust average value (reference values) for the examined HMs (Taylor and McLennan 1995) to compare the obtained results. Based on this comparison, the average concentration of Mn and Cr was lower than the Earth's crust average value, while the average concentration of As, Cu, Hg, Ni, Pb, and Zn was higher than the Earth's crust average value. The other remarkable result is that As average concentration (7.66 mg kg^{-1}) was approximately five-fold of the Earth's crust's average (1.5 mg kg^{-1}).

The highest mean value was found to be Mn (568.79 mg kg^{-1}), followed by Zn (87.94 mg kg^{-1}), Cu (46.76 mg kg^{-1}), Cr (30.25 mg kg^{-1}), Ni (22.93 mg kg^{-1}), Pb (22.36 mg kg^{-1}), As (7.66 mg kg^{-1}), and Hg (1.59 mg kg^{-1}). The mean concentrations of Cr and Mn were slightly lower than the Earth's crust's average background value for soils worldwide, whereas the mean concentrations of the remaining six heavy metals all exceeded the corresponding background values for soils in Earth's crust. The average concentrations of Cr, Cu, Ni, Pb, and Zn measured in outdoor dust in this study were less than in global studies(Aguilera et al. 2021; Long et al. 2021).

Abrasion processes in tires, brake wear, and corrosion of vehicle components, as well as outdoor infrastructure, are linked to the origin of Zn, As, and Pb (Lough et al. 2005; Salma and Maenhaut 2006; López et al. 2011). In the present study area, the distribution chart of As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn with the average value of each heavy metal is shown in Fig 2 . Also, the world average levels of heavy metals described above are shown in the chart for comparison. (See Fig.2).

Table 2. The average concentration of HMs (mg kg^{-1}) in outdoor dust collected from the study area and Earth's crust average (Taylor and McLennan 1995)

3.2 Risk assessment

3.2.1 Pollution index assessment

The average pollution index (PI) of all examined HMs is listed in descending order as follows: As (5.22) > Hg (5.15) > Cu (1.93) > Ni (1.21) > Zn (1.16) >Pb (1.15) >Mn (1.11)> Cr(0.99) (Table. 3). According to (Hakanson 1980) developed model As and Hg indicated considerable contamination level. Whilst, Mn, Cu, Ni, Pb, and Zn shown moderate contamination levels. Only

Cr was included in the insignificant contamination category. The pollutant load index (PLI) of each sampling site was calculated and presented in Table 3. The average pollutant load index (PLI) in the studied area of 8.85 (>3) was estimated at a high pollution level. The comparable results of the heavy metal analysis in outdoor dust were reported in Ordu (2.5), Artvin (2.1), Samsun (1.8), Giresun (1.6), and Trabzon (1.2) as polluted category(Yesilkanat and Kobya 2021). The boxplot of the pollution index (PI) with four contamination categories is presented in Fig 3.

Table 3. Calculated values of the pollution index (PI) factor of each metal, the pollutant load index (PLI), and pollution category (PC) for metals in outdoor dust in study area

Fig 2. The scatter plot of heavy metals measured value along with the world average level in the study area

Fig. 3 Box-plot of pollution index (PI) in the studied area outdoor dust samples (The grey point, cross points and boxes mark are represents mean, median, and 25^{th} and 75^{th} percentile values., respectively. Classification of pollution areas separated by dashed lines.

3.2.2 The non-carcinogenic assessments

For non-carcinogenic risk, the hazard quotient (HQ) and hazard index (HI) parameter were calculated. The HQ and HI values of heavy metals for both adults and children in different exposure routes (ingestion, inhalation, and dermal contact) were estimated and the results have been shown in Table 4. Ingestion was found to be the most common method of HMs in outdoor dust exposure, followed by inhalation, and dermal contact was found to be the least common pathway, which was comparable to (Taiwo et al. 2020; Gupta et al. 2022). The following is a list of the three exposure paths for children and adults, in decreasing order of HM intake: Mn > Zn > Cu > Cr > Ni > Pb > As > Hg. The HI values of the HMs were found 1.77E-03 and 8.66E-04 for adults and children, respectively. Based on the results of the analysis, the HI values were found to be lower than the safe level (HI < 1) for adults and children indicate that there are no adverse effects on adults or children that are non-carcinogenic (Fig.4). As seen in fig.4, the adult's average hazard index (HI) is approximately 2 times more than children average hazard index.
The hazard quotient (HQ) distribution due to HMs in the studied area for children and adults were presented in Fig 5. As shown in this figure, As elements indicated a significant range in adults.

3.2.3 The carcinogenic assessments

As shown in Table 5, the lifetime average daily dose (LADD) levels through three different exposure pathways: inhalation, ingestion, and contact with the skin; as well as incremental lifetime cancer risk figures for all HMs in outdoor dust have been calculated and summarized. Also, like no-carcinogenic, ingestion was found to be the most common method of outdoor dust HMs exposure, followed by inhalation, and dermal contact was found to be the least common pathway of outdoor dust HM exposure in the study area.

According to the results of the ILTCR calculations, the order of the ILTCR values for HMs is Zn > Mn > Cu > Cr > Ni > Pb>As > Hg. The results of incremental lifetime cancer risk assessment showed that ILTCR values for Mn, Cu, and Zn through all three paths were higher than 1.00E–6, suggesting that using outdoor dust to study potentially toxic HMs is associated with a considerable amount of carcinogenic risk. As a result, the level of carcinogenic risk calculated according to the Environmental Protection Agency of the U.S for the study area was within the range of acceptable levels (Means 1989). Figure 6 presents the box plot of ILTCR parameters for HMs in the outdoor dust samples in the study area. The figure shows that Zn contribution to the ILCR parameter was significant. According to (Chen et al. 2012) there is evidence that Zn contributes to urban dust not only via industrial sources but as well from traffic and garbage. Results suggested that traffic emissions and industrial pollutants are significant sources of HM enrichment in the study area.

Table. 4 The hazard index (HI) for non-carcinogenic risk and hazard quotient (HQ) of the children and adults in the study area (n=54)

Table. 5 The lifetime average daily dose of inhalation ($LADD_{inh}$), dermal ($LADD_{der}$), ingestion ($LADD_{ing}$), and incremental lifetime cancer risk ILTCR in the study area (n=54)

Fig. 4 The dissemination of HI parameter for adults and children group

Fig. 5 The hazard quotion (HQ) distribution range for adults and children

Fig. 6 The box plot of incremental lifetime cancer risk ILTCR in the studied area outdoor dust

3.4 Statistical assessments

All of the metals examined in this study were correlated using Pearson coefficients in order to establish inter-element relationships within the outdoor dust samples. The correlation matrix obtained from the correlation analysis is shown in Table 6. In comparison with other heavy metals, all of the pairs except Cu - As (-0.683) and Ni - Mn (-0.608) showed a significant correlation. A significant correlation was also observed between Cr and As (0.620), As and Pb (0.657), Mn and Zn (0.671), Cr and Ni (0.465), Cu and Pb (0.457), whereas no significant correlation was observed between Cr and As (0.620). Some metals, including Cr, Cu, Ni, and Zn, have similar characteristics and may have acquired their emissions from similar sources. It is possible to produce Zn, Ni, Cu, and Cr from the wear and tear of tires and brakes (Amato et al. 2011; Bourliva et al. 2017).

Table 6. The HMs concentration values correlation coefficients in examined samples
(*The bold values were indicated as statistically significant)

To examine the classification of element groups in the outdoor dust data and to identify relationships among them, the cluster analysis method was employed for the data analysis and the classification of element groups. A diagram representing the results of the analysis is shown in Fig.7. The similarity index is represented by the vertical line, and the greater the value, the greater the significance of the association between the variables. The cluster analysis of the data shows two distinct subgroups of metals, the first of which contains Cu, Mn, and Zn, and the second of which includes Ni, Cr, Pb, Hg, and As. According to the results, Mn - Zn had the strongest association (similarity > 80 %), whereas As - Pb had the weakest association. In subgroup 3, Cr and Ni were also found to have a strong association with each other.

Also, the factor analyses of HMs concentration values were performed and presented in Figure 8. As shown in this graph, the HMs was divided into four groups. The elements of Ni - Hg are in the (1, 1) group, Cu in (1,-1), Zn -Mn in (-1,-1), and Cr, As, and Pb in the (-1, 1) group. (See Figure8)

Fig. 7 The HMs concentration and using cluster analysis of the variables

Fig. 8 The factor analyses of HMs concentration in outdoor dust

4. Conclusion

Nineteen outdoor dust sampling sites with fifty-four samples were selected to investigate heavy metals in the dust contamination due to traffic and the outdoor dust of the Eastern Mediterranean Sea area. The concentration of HMs elements in outdoor dust was elucidated. It was found that the level of heavy metal pollution in the study area was higher than that of the Earth's crust average value except for Mn and Cr. The main sources of heavy metals in outdoor dust appear to be traffic emissions and industrial sources.

The ecological-human-health-risk-assessment parameter (EHHRA) was calculated in the study area. The calculated results of EF and PLI showed that the studied area was detected in different pollution levels and the pollution in the forms of As and Hg was severe level. Regarding the risk to human health, the HQ and HI parameters for the non-carcinogenic risk of the children and adults was calculated. The highest HQ for adults and children was obtained due to As and Cr, respectively. Lifetime average daily dose (LADD) and incremental lifetime cancer risk (ILCR) were assessed for carcinogenic risk. The LADD parameter estimation indicated that the ingestion pathway is the main exposure way. Additionally, Zn and Mn indicated a significant value for LADD. According to the US-EPA health risk assessment methodology, no metal exceeded the acceptable cancer risk range of 1×10^{-6} to 1×10^{-4}. Hence, the cancer risk to human ratio in study area looks to be negligible.

Ethical Approval

The authors approvals the ethical responsibilities.

Consent to Participate

Approved.

Consent to Publish

Approved.

Authors Contributions

Akbar Abbasi: Investigation, Conceptualization, Methodology, Software, Project administration, Visualization, Writing- Original draft preparation. **Fatemeh Mirekhtiary:** Draft preparation, Software, Writing. **Hesham MH. Zakaly:** Methodology, Software, Writing- Original draft preparation, Writing- Review& Editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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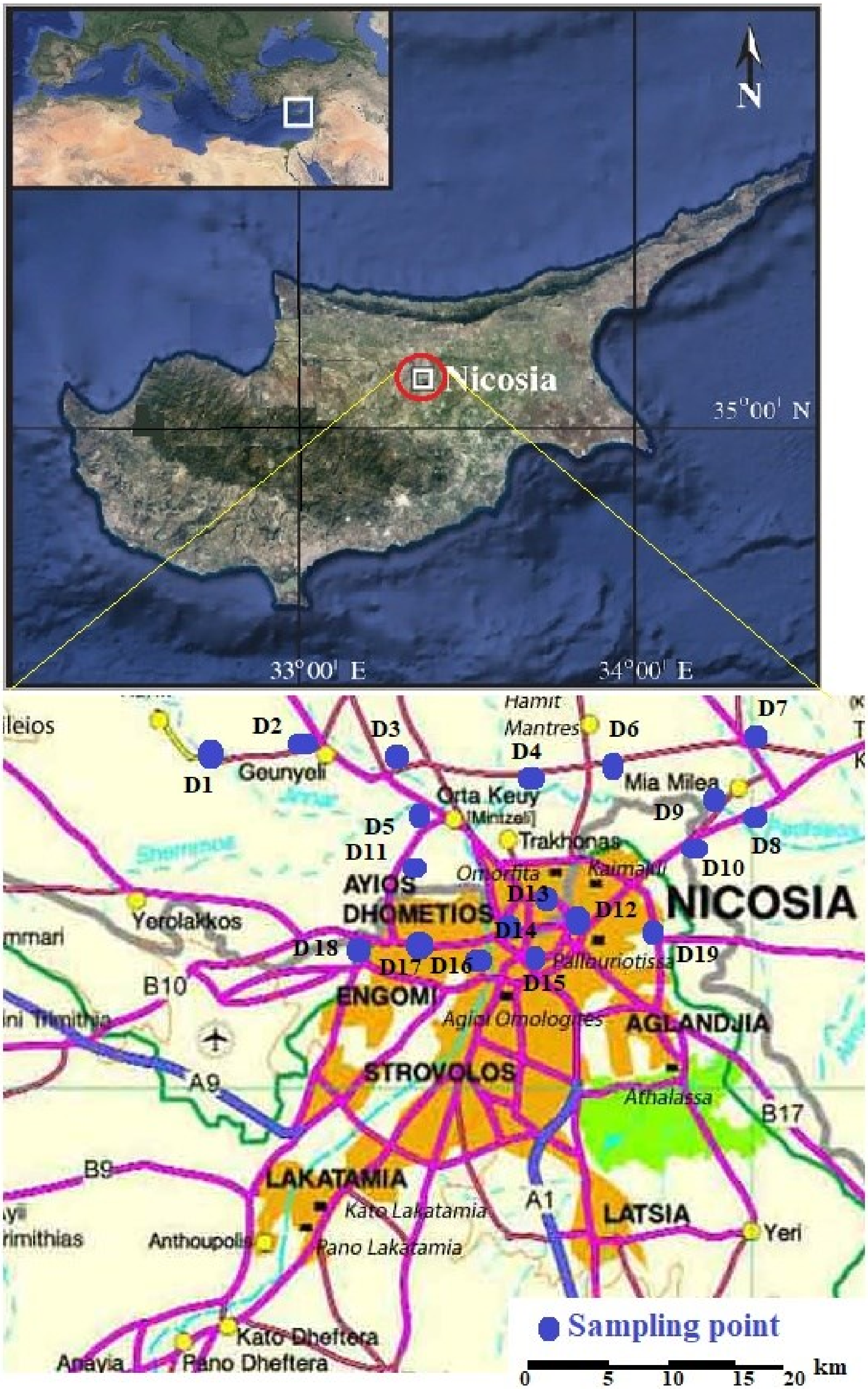

Fig 1. Geographical location and sampling sites in the study area

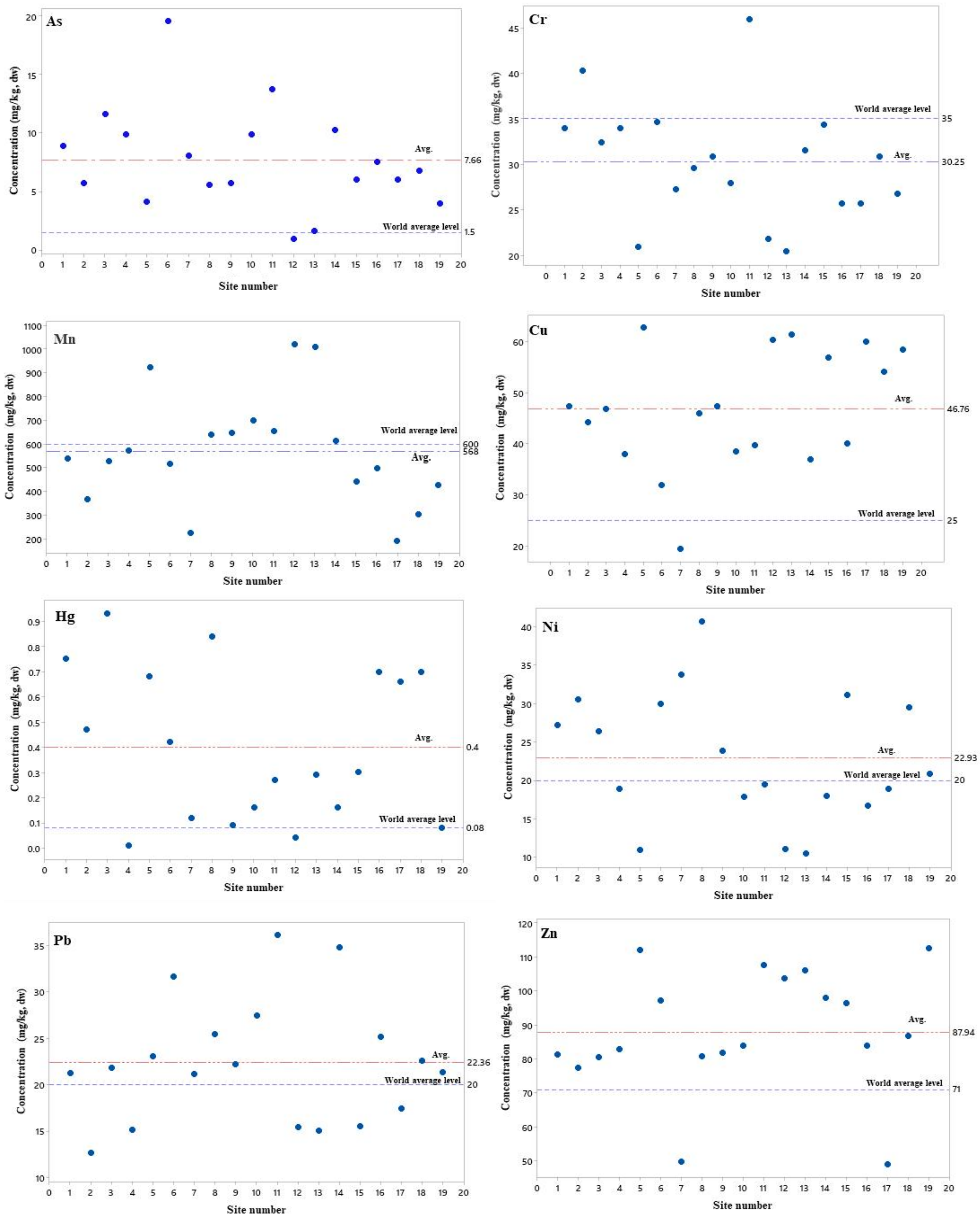

Fig 2. The scatterplot of As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn along with the world average level in the study area

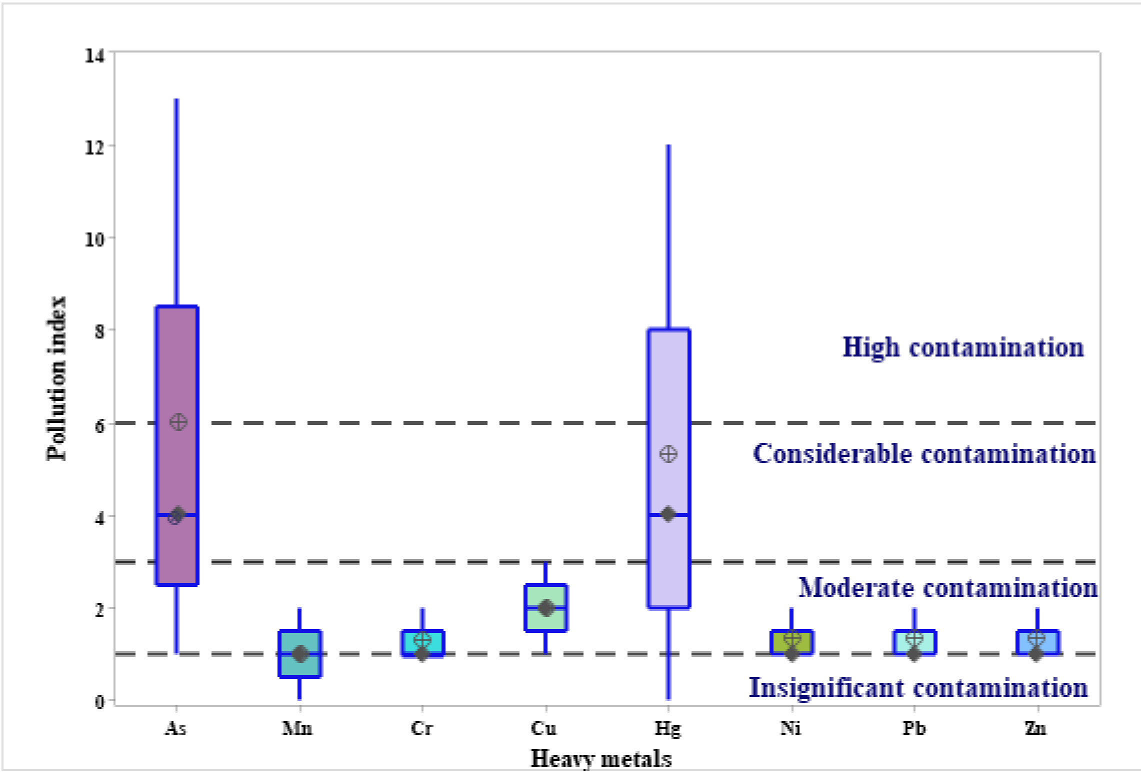

Fig. 3 Box-plot of pollution index (PI) in the studied area road dust samples (The grey point, cross points and boxes mark are represents mean, median, and 25^{th} and 75^{th} percentile values., respectively. Classification of pollution areas separated by dashed lines.

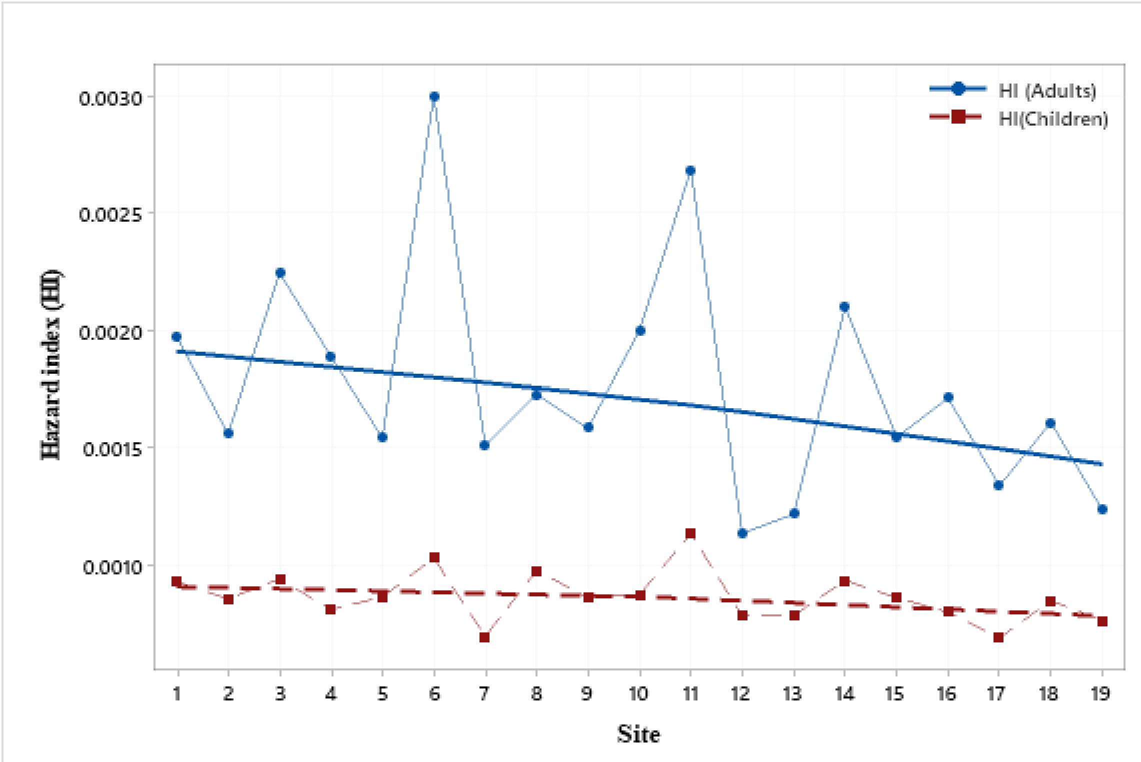

Fig. 4 The distribution of hazard index (HI) for adults and children group

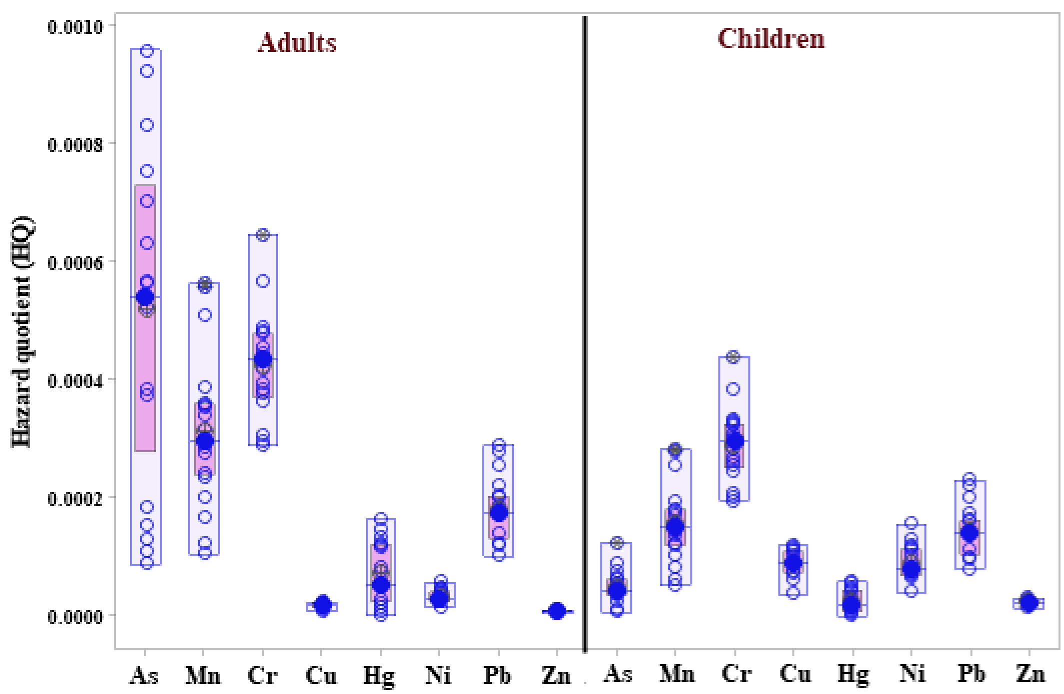

Fig. 5 The hazard quotion (HQ) distribution range for adults and children

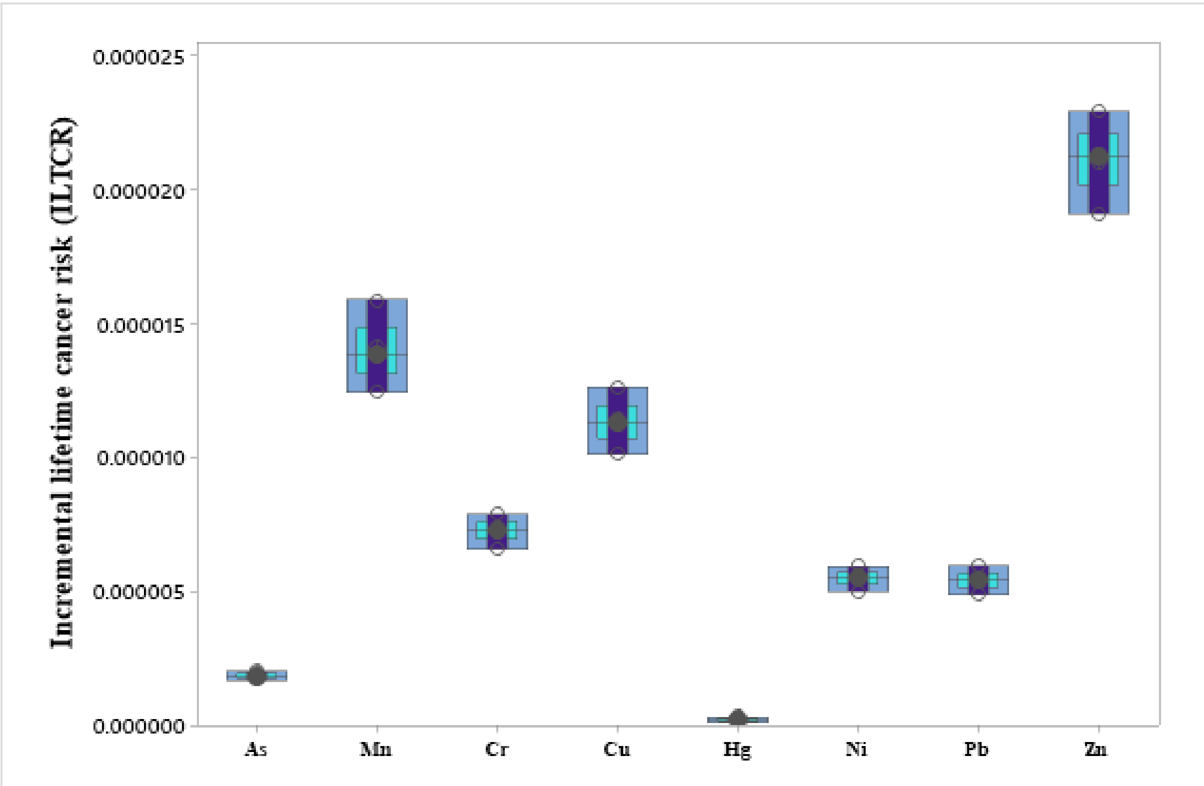

Fig. 6 The box plot of incremental lifetime cancer risk ILTCR in the studied area road dust

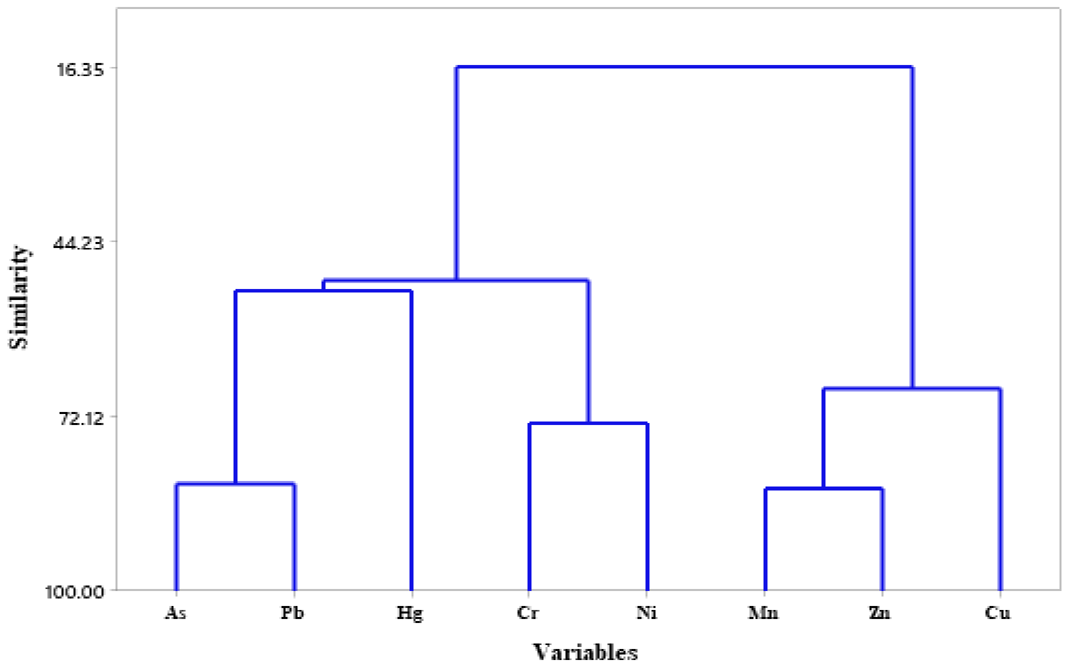

Fig. 7 Cluster analysis of variables of As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn concentration

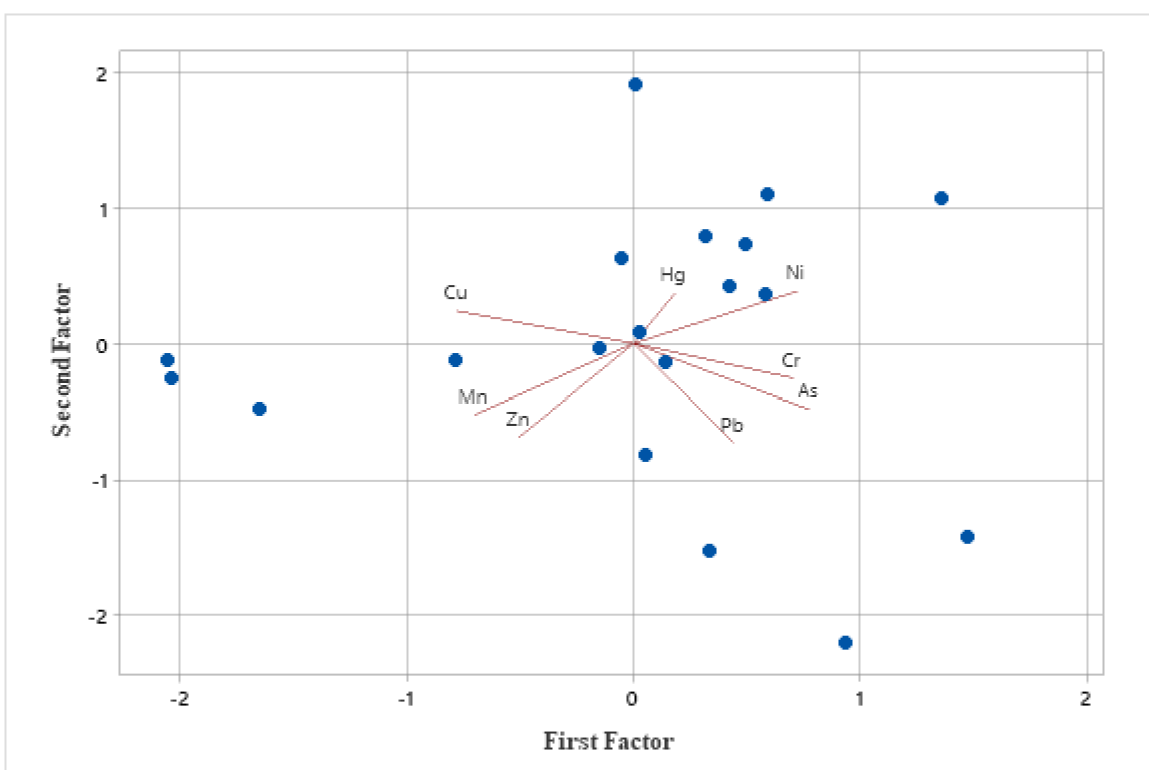

Fig. 8 The factor analyses of As, Mn, Cr, Cu, Hg, Ni, Pb, and Zn elements in road dust

Table 1. Variables and parameters of exposure applied in risk assessment calculation.

Variables	Definition	Adult	Children	General	References
C_{dust}(mg/kg)	Heavy metal concentration in outdoor dust			Calculated	This study
BW (kg)	Body weight	70	15		(USEPA, 1989)
InhR (m^3/day)	Inhalation rate	7.6	20		(EPA, 1996)
IngR (mg/day)	Ingestion rate	100	200		
EF (d/y)	Exposure frequency			180	
ED (y)	Exposure duration	24	6		(EPA, 2001)
$AT_{carc}(d)$	Averaging time for a carcinogenic effect			70 x 365	
$AT_{noncarc}(d)$	Averaging time for non-carcinogenic effect			ED x 365	
SA (cm^2)	Surface area of skin exposed	5700	2800		
AF (mg/cm/day)	Skin adherence factor for dust	0.7	0.2		
PEF (m^3/kg)	Particle emiDion factor			1.36×10^9	
ABS	Absorption skin factor			0.001	
CF	Conversion factor			1.00×10^{-6}	

Table 2. The average concentration of heavy metals (mg kg^{-1}) in outdoor dust collected from the study area and Earth's crust average value (Taylor and McLennan, 1995)

Region	Sites (#)	**HMs** (mg/kg, dw)*							
		As	**Mn**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
Karpaz	D-1 (n=3)	8.86	539.08	33.95	47.29	0.75	27.13	21.24	81.17
	D-2 (n=3)	5.74	366.23	40.26	44.16	0.47	30.47	12.6	77.36
	D-3 (n=3)	11.64	528.93	32.42	46.74	0.93	26.34	21.84	80.59
Famagusta	D-4 (n=3)	9.84	571.32	33.92	37.90	0.01	18.88	15.12	82.84
	D-5 (n=3)	4.10	922.32	20.90	62.56	0.68	10.94	23.08	112.12
	D-6 (n=3)	19.52	516.83	34.66	31.83	0.42	29.99	31.68	97.24
	D-7 (n=2)	8.04	223.45	27.21	19.50	0.12	33.79	21.16	49.74
Kyrenia	D-8 (n=3)	5.58	638.62	29.58	45.91	0.84	40.64	25.4	80.78
	D-9 (n=3)	5.74	647.66	30.89	47.20	0.09	23.78	22.14	81.66
	D-10 (n=2)	9.84	698.94	27.94	38.46	0.16	17.89	27.48	83.92

	D-11 (n=3)	13.69	654.19	45.90	39.65	0.27	19.50	36.1	107.52
Lefke	D-12 (n=3)	0.94	1019.70	21.77	60.17	0.04	11.03	15.36	103.60
	D-13 (n=2)	1.62	1009.14	20.46	61.27	0.29	10.48	14.98	106.05
	D-14 (n=3)	10.21	613.34	31.57	36.89	0.16	17.91	34.82	98.02
	D-15 (n=3)	6.03	440.09	34.36	56.76	0.30	31.13	15.47	96.26
Nicosia	D-16 (n=3)	7.49	497.76	25.74	39.93	0.70	16.63	25.16	83.82
	D-17 (n=2)	5.99	190.08	25.73	59.89	0.66	18.83	17.45	48.96
	D-18 (n=3)	6.74	301.58	30.82	53.91	0.70	29.47	22.59	86.85
	D-19 (n=3)	3.99	427.78	26.76	58.33	0.08	20.78	21.34	112.41
Min-Max		0.94-19.52	190.08-1019.7	20.46-45.9	19.5-62.56	0.01-0.93	10.48-40.64	12. 6-36.1	48.96-112.41
Mean		7.66	568.79	30.25	46.76	0.40	22.93	22.36	87.94
Kurtosis		2.03	0.01	0.76	-0.01	3.72	-0.51	-0.09	0.63
Skewness		1.03	0.47	0.58	-0.47	1.22	0.27	0.75	-0.76
Earth's crust average value		1.5	600	35	25	0.08	20	20	71

*Uncertainties are given within 1 standard deviation

Table 3. Calculated values of the pollution index (PI) factor of each metal, the pollutant load index (PLI), and pollution category (PC) for metals in road dust from different traffic areas of Nicosia, Cyprus

Sites	PI								PLI	Pollution Category
	As	Mn	Cr	Cu	Hg	Ni	Pb	Zn		
D-1	6	1	1	2	9	1	1	1	18.7	C
D-2	4	1	1	2	6	2	1	1	3.7	C
D-3	8	1	1	2	12	1	1	1	28.2	C
D-4	7	1	1	2	0	1	1	1	0.1	A
D-5	3	2	1	3	9	1	1	2	6.7	C
D-6	13	1	1	1	5	1	2	1	30.2	C
D-7	5	0	1	1	2	2	1	1	0.3	A
D-8	4	1	1	2	11	2	1	1	23.7	C
D-9	4	1	1	2	1	1	1	1	1	B
D-10	7	1	1	2	2	1	1	1	3.3	C
D-11	9	1	1	2	3	1	2	2	23.4	C
D-12	1	2	1	2	1	1	1	1	0.1	A
D-13	1	2	1	2	4	1	1	1	0.7	A
D-14	7	1	1	1	2	1	2	1	4.9	C
D-15	4	1	1	2	4	2	1	1	5.1	C

D-16	5	1	1	2	9	1	1	1	6.6	C
D-17	4	0	1	2	8	1	1	1	1.3	B
D-18	4	1	0.9	2	9	1	1	1	9.6	C
D-19	3	1	1	2	1	1	1	2	0.7	A
Avg.	5.22	1.11	0.99	1.89	5.15	1.21	1.15	1.16	8.85	-

Table. 4 Hazard Quotient (HQ) and Hazard Index (HI) for non-carcinogenic risk of the children and adults in the study area (n=19)

Element	Adult					Children		
	ADDinh	ADDing	ADDder	HQ	HI	ADDinh	ADDing	ADDder
As	3.02E-10	2.15E-07	2.11E-10	7.20E-04	1.77E-03	3.70E-09	1.41E-07	1.97E-09
Mn	2.24E-08	1.6E-05	1.57E-08	3.14E-04		2.75E-07	1.05E-05	1.46E-07
Cr	1.19E-09	8.5E-07	8.34E-10	4.26E-04		1.46E-08	5.57E-07	7.79E-09
Cu	1.84E-09	1.31E-06	1.29E-09	1.78E-05		2.26E-08	8.61E-07	1.20E-08
Hg	1.59E-11	1.13E-08	1.11E-11	7.10E-05		1.95E-10	7.43E-09	1.04E-10
Ni	9.03E-10	6.44E-07	6.32E-10	3.23E-05		1.11E-08	4.22E-07	5.90E-09
Pb	8.81E-10	6.29E-07	6.17E-10	1.80E-04		1.08E-08	4.12E-07	5.76E-09

Table. 5 Lifetime average daily dose of inhalation (LADDinh), derma (LADDder), ingestion (LADDing), and incremental lifetime cancer risk **ILTCR** in the study area (n=19)

Element	LADDinh	LADDing	LADDder	ILTCR
As	1.04E-10	7.37E-08	7.23E-11	1.84E-06
Mn	7.68E-09	5.49E-06	5.38E-09	1.38E-05
Cr	4.08E-10	2.91E-07	2.86E-10	7.29E-06
Cu	6.31E-10	4.49E-07	4.42E-10	1.12E-05
Hg	5.45E-12	3.87E-09	3.81E-12	9.69E-08
Ni	3.10E-10	2.21E-07	2.17E-10	5.52E-06
Pb	3.02E-10	2.16E-07	2.12E-10	5.39E-06
Zn	1.19E-09	8.47E-07	8.30E-10	2.12E-05

Table .6 Pearson correlation coefficients between HMs concentration values in bold are statistically significant

	As	Mn	Cr	Cu	Hg	Ni	Pb	Zn
As	1							
Mn	0.290	1						
Cr	**0.620***	0.367	1					
Cu	**- 0.673***	0.354	0.428	1				
Hg	0.089	0.197	0.008	0.198	1			
Ni	0.299	**- 0.608***	**0.465***	0.412	0.311	1		
Pb	**0.657***	0.036	0.315	**0.457***	0.042	0.036	1	
Zn	-0.078	**0.671***	-0.035	0.403	-0.209	-0.446	0.237	1

* $p < 0.05$