Origin and Risk Assessment, and Evaluation of Heavy Metal Pollution in the Soil of Tehran, Iran

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ABSTRACT: *In this research, the concentrations of several heavy metals such as chromium (Cr), arsenic (As), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd) were measured using Enrichment Factor (EF), chemical separation, pollution index (Ipoll), ecological Risk Index (RI), and health risk assessments. The results of the soil EF showed that Cr, As, Ni, Zn, and Cu are at a minimum limit of pollution while Pb is at a moderate limit of pollution, and Cd has a significant level of pollution in the soil. The results of the chemical separation of anthropogenic and lithogenous phases demonstrated that the studied elements were of low pollution, except Cd. Based on Ipoll results, all metals were in the non-pollution zone except for Cd. The ER results of the metals in the soil of all metals were low except for Cd. According to USEPA guidelines, the risk of cancer from As, Ni, and Cr metals is high; the risk of Pb is medium; and the risk of Cd is low. The total risk of 9.68E-03 is unacceptable in the risk range because inhalation, ingestion, and skin contact with heavy metals increase cancer risk. During their average life expectancy of 70 years, 3,739 people develop various types of cancer. All metals' hazard quotient (HQ) is lower than the safe level one in the non-cancer risk assessment. Even so, the total hazard index (HI) of 1.52E + 00 is more than 1, indicating that people are exposed to a variety of non-cancerous diseases due to breathing, swallowing, or skin contact with these metals. Eventually, Monte Carlo simulation uncertainty results in support of the results of cancer and non-cancer risk analysis. Overall, it is concluded that proper management strategies are required to control the concentration of these pollutants in Tehran's soil to maintain the health of Tehran's citizens.*

KEYWORDS: *Urban environment; Pollution; Soil; Toxic metals; Anthropogenic fraction.*

INTRODUCTION

Soil is an essential element of the environment that forms the ecosystem. In addition, it provides the basis for plant and animal productivity and supports human survival and growth [1]. Currently, soil pollution by heavy metals is one of the most important environmental concerns. According to many environmental studies, heavy metals are potentially harmful substances released from human activities that pose risks for the surrounding environment and human health. The increasing growth of pollution by heavy metals in environmental components leads to a global risk increase for human health and the environment. Soil pollution by toxic and hazardous compounds causes the destruction or disappearance of some soil functions worldwide [2]. The rapid development of urbanization and

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the expansion of industrial sectors in cities and their surroundings are specifically due to the accumulation and pollution of heavy metals in the urban soil. Typically, the heavy metals of the soil intensively enter the urban environment through municipal wastes, waste disposal, industrial effluents, greenhouse gas emissions of vehicles, construction wastes, and the heavy use of agricultural chemical materials [3]. Urbanization processes have altered the intrinsic properties of damaged soils, such as their pH, texture, cation exchange capacity, and bulk concentration, and inadvertently caused the deposition of harmful substances such as heavy metals in the soil [4]. Further, heavy metals have been extensively applied as a criterion for human pollution due to their association with human activities and environmental sustainability [5]. Heavy metal pollution has a long-lasting period, a small amount of transfer, severe toxicity, concealment, complex chemical properties, and ecological response, and is irreversible. Therefore, it has become the most serious problem in soil pollution [6]. In addition, heavy metals tend to accumulate in the soil due to their non-biodegradable property and significantly change the soil ecosystem by reducing soil quality. Heavy metals can also be easily transported into water bodies through soil erosion [7]. A surface runoff slowly percolates into the soil media. This runoff, which can persist for a longer period in contact with the visceral of soil media, becomes saturated with minerals in the dissolved form [8]. Chronic exposure to heavy metals has harmful consequences for humans, including lung cancer, bone fracture, and kidney dysfunction. Exposure can lead to cholesterol, fertility, liver, immune system, nervous, and endocrine dysfunctions. The consumption of heavy metals by humans can damage the nervous, skeletal, and blood circulation, enzymatic, endocrine, and immune systems [4,9]. The potential for exposure to pollutants through oral, inhalation, and dermal pathways has been recognized as an important route that can have a basic impact on human health. Regarding the expansion of environmental pollution in recent years, pollution management has been the subject of intense research [10]. The sources of heavy metals are of human or natural types [11]. These metals are typically present in the atmosphere, lithosphere, hydrosphere, and biosphere [12]. In this respect, the natural resources of heavy metals include erosion, mineral weathering, volcanic activity, and other geological processes [13,14]. Heavy metals, such as industries, greenhouse gas emissions, household waste disposal, mining, smelting, and agricultural activities, contribute to human resources [12]. Furthermore, previous studies indicate that humans are exposed to heavy metals by swallowing, inhalation, and absorption through the skin [12,15-21]. Other studies demonstrated that the adverse effects of heavy metal exposure and human health, even at low concentrations, are not limited to neurological and carcinogenic problems [22-26]. Prolonged contact with heavy metals at low concentrations can be dangerous to humans [21] and cause negative effects on the immune system and endocrine glands or cancer in adults and children [27]. Although some metals like Cu, Fe, Mn, Ni, and Zn are essential as micronutrients for life processes in plants and microorganisms, many other metals like Cd, Cr, and Pb are proved detrimental beyond a certain limit [28]. Due to the great diversity of resources, persistent toxicity, non-degradability, and biological accumulation, soil pollution with heavy metals have continuously been an environmental problem [29,30,31,32]. Heavy metals are naturally stable and thus accumulate in the soil and plants [33]. According to a study on the dangers of heavy metals in the ground in Kazakhstan, the non-cancer risk results revealed that Pb has a Hazard Quotient (HQ) of more than 1, while this value was less than 1 for Cd, Cu, Zn, and Cr. The 1.93E + 00 total hazard index (HI) was greater than 1, indicating the possibility of non-cancerous diseases. According to the USEPA guideline, cancer risk for all age groups is in the range of 1.00E 06, suggesting its non-significant health effects [34].

According to the findings of a study on non-cancer risk assessment in Manus, Brazil, metals have an HQ < 1. Therefore, people are not at risk for non-cancerous health effects; however, the cancer risk of Cs and Pb is not low enough to be considered safe such that long-term exposure to contaminated soils increases the risk of cancer in children [35]. The risk of heavy metals in urban soils was assessed in a study called “Fractionation of Potentially Toxic Elements (PTEs) in Urban Soils from Salzburg, Thessaloniki, and Belgrade: An Insight into Source Identification and Human Health Risk Assessment” Pb> As> Ni> Zn> Cu> Cr and Pb> As> Ni> Cu> Zn> Cr were the non-cancer HQs for children and adults, respectively. There was no non-cancer risk, and the total HI for both age groups was less than one. As was higher than Pb, and Ni was lower than As. Finally, the findings show no risk of cancer or non-cancer in children and adults [36]. In a study in Yazd, Iran, toxic metals showed adverse effects on human health. The risk assessment results revealed oral consumption as the main route for the consequent damages. Overall, the metals showed cancer risks in the following order: Ni> Pb> Cr> As> Cd. Although metals have an acceptable carcinogenic risk for adults, the metals Cr, Pb, and Ni raise cancer risk in children [37].

Regarding the mentioned points, this study mainly aims to present the distribution map and description of the dispersal of selected heavy metals in the soil of Tehran, the chemical dissociation of soil samples, and the determination of the percentage of human and lithogenic origin of metals. The study further seeks to evaluate heavy metal contamination in the soil using several methods: pollution index, enrichment factor (EF), ecological risk index (ERI), and toxicity characteristic leaching procedure. Finally, it attempts to assess the health risks of heavy metals in the soil of Tehran. The results of this study indicate the origin and contamination of heavy metals and their health risks to people's health. They also provide scientific evidence to completely manage most of these urban pollutants and help managers take the necessary measures to control heavy metal pollution.

EXPERIMENTAL SECTION

Study area

Tehran, the largest city of Iran, is located between 3,952,446.93 of northing latitude and 536,573.11 of easting longitude. As the largest and most populous city in the country, Tehran faces several environmental challenges such as suffering from pollution problems due to its special geographical (meteorological topography), social (population distribution and traffic), and cultural (the level of culture and education) conditions and urban development [38]. Sampling was performed from the entire city from its 22 municipality districts (Fig. 1).

Sampling and heavy metals analysis were done monthly in the whole territory of Tehran from April 2019 to March 2020. Since urban soil samples are considered, urban parks, green lands, and side streets were selected as sampling points [39- 43].

Soil sampling

The soil environmental monitoring aims to examine the presence or absence of various heavy metal contaminants

Fig. 1: Location map of the study area.

in the soil environment. Likewise, the concentration of each pollution should be determined effectively in the case of soil contamination. In this way, it is possible to estimate the degree of risk and the danger to humans in contact with the contaminated soil. Based on its type and nature, the pollutant concentration is calculated by chemical methods and instrumental analysis. In the present study, monitoring was performed to scrutinize the soil in direct contact with humans, and topsoil was sampled radially from each district (0 to 15 cm from the topsoil). A central sampling point was selected, and then samples were taken from four directions around the center point by auger and hand shovel. Afterward, the collected samples from five points were mixed homogeneously and labeled as a single sample of the desired station in the relevant zip kip. Eventually, as a sample from any target point of monitoring, these five samples were combined and sent to the laboratory. This study focused on measuring the concentrations of Nickel (Ni), Copper (Cu), Zinc (Zn), Lead (Pb), Chromium (Cr), Arsenic (As), and Cadmium (Cd) in the soil of the Tehran metropolis.

First, about 5 mL of fluoric acid (HF) was added to the sample and heated on a sand bath at 125°C. Next, the Teflon beaker was placed on the sand bath until the white smoke came out, and then the beaker was immediately removed from the sand bath. The next dissociating solution (HF) was added to dissociate the silicates. After ensuring the evaporation of HF, the elements attached to it were separated. The second-stage solution was highly dissimilar. The addition of nitric acid, some hydrochloric acid, and nitric acid (3 mL of nitric acid and 1 mL of hydrochloric acid) is an extremely strong mix and produces a new acid called acetic acid. Approximately

7 mL of aqua regia was added to the sample and heated again on a sand bath at 125°C. After evaporating about 6.5 mL of this 7 mL of acid, the sample was removed from the sand bath. The organic substance was completely dissociated using 3 mL of perchloric acid. Next, the sample was heated to the drying boundary and removed from the sand bath to equilibrate its temperature with the laboratory room temperature [44]. Finally, the samples were analyzed using an Inductively Coupled Plasma Mass- PerkinElmer (ICP-MASS) device (ELAN 9000 USA, Spectrometry).

Spatial distribution and interpolation

ArcGIS 10.3 software and the Kriging method were used in this research. The cross-validation technique was applied to validate the models. In this method, two Root mean square (RMS) and Root mean square standard (RMSS) values were considered to assess the models. The reason for choosing these measures is that the spherical model is appropriate for zoning and predicting the level of metals in the study area.

Chemical partitioning

In the chemical partitioning method, 2 grams of a soil sample is heated to 15 mL of normal 0.53 HCl. This substance will lead to loose and sulfide bond failure. Then, the suspension is shaken for 30 min, and it reaches a volume of 50 mL. Finally, the samples were analyzed using an ICP-MASS device. The obtained concentration minus 10% of the total concentration indicates the anthropogenic degree of metals [39,45].

Pollution Index (I_{poll})

The Müller-Swiss formula can be optimized or modified because the chemical partitioning method separates the anthropogenic part from the natural one. Consequently, the normal concentration is obtained, and no correction factor is needed for balance (1.5). To this end, the formula was changed from Eq. (1) to Eq. (2), as follows [46].

$$I_{geo} = \log_2[cn/1.5B_n] \quad (1)$$

$$I_{poll} = \log_2[cn/B_n] \quad (2)$$

According to this index, soils are classified into seven different groups (Table 1). In this way, the number of metals can be measured concerning their normal amount, and the level of soil pollution can be determined.

Table 1: Guide to the geochemicala of the heavy metal index in the soil.

unpolluted	$0<I_{poll}\leq 1$
unpolluted to moderately polluted	$1<I_{poll}\leq 2$
moderately polluted	$2<I_{poll}\leq 3$
moderately to highly polluted	$3<I_{poll}\leq 4$
highly polluted	$4<I_{poll}\leq 5$
very highly polluted	$I_{poll}>5$

Ecological Risk Index (RI)

An ecological RI was suggested by *Hakanson* [47] to evaluate pollution status. The RI of heavy metals is calculated by Eqs. (3-5) as follows:

$$CF^i = Cs^i \times Cn^i \quad (3)$$

$$Ei = CF^i \times Tf^i \quad (4)$$

$$IR = \sum_{i=1}^{6} Ei \quad (5)$$

where Ei is an individual potential hazard, and Tf^i denotes the coefficient of toxicity for metals. In the current study, reference toxicity values were adopted for each heavy metal as Zn = 1, Cr = 2, Cu = 5, Pb = 5, As = 10, and Cd = 30 [48]. As shown in Table 2, EI and RI values are categorized into five levels.

Enrichment Factor (EF)

The EF is used to differentiate between human, natural, or mixed resources (human and natural), regulate the degree of heavy metal contamination, and evaluate the anthropogenic effect. This factor is based on the standardization of a tested element against a reference element. The EF of an element is calculated using Eq. (6):

$$EF= (Cn/C_{Fe})_{sample}/ (Cn/C_{Fe})_{background} \quad (6)$$

where $(Cn/C_{Fe})_{sample}$ and $(Cn/C_{Fe})_{background}$ are the concentration of metals in the soil sample and the reference concentration, respectively. Also, Fe was used as a normalizing element [49]. Based on the results of most studies, the EF between 0.5 and 2 has a terrestrial origin, and values above 2 are attributed to human activities [50-52]. According to *Keshavarzi* and *Kumar* [49], contamination degree can be indicated by the EF through five levels ranging minimal enrichment (EF < 2), moderate

Table 2: Ei and RI classification.

Ei		RI	
Low risk	Ei < 40	Low risk	RI < 150
Moderate risk	40 <Ei < 80	Moderate risk	150 ≤ RI < 300
Significant risk	80 < Ei < 160	Significant risk	300 ≤ RI < 600
High risk	160 < Ei < 320	Serious risk	RI ≥ 600
Serious risk	Ei ≥ 320		

enrichment (2 ≤ EF < 5), significant enrichment, 5 ≤ EF < 20), very high enrichment (20 ≤ EF < 40), and extremely high enrichment (EF ≥ 40).

Risk assessment

Carcinogenic risk

Regarding assessing cancerous effects, even the smallest amount of human contact with the desired pollution will increase the risk of cancer incidence in humans. Carcinogenic Chronic Daily Intake (CDI) through inhalation, oral, and dermal exposure pathways was calculated using Eqs. (7-10) as follows [53]:

$$CDI_{Inhalation-air} = \frac{C \times EF \times ED \times ET \times (1\ day/24hours)}{AT} \quad (7)$$

$$CDI_{oral-soil} = \frac{C \times IFS \times RBA \times 10^{-6}}{AT} \quad (8)$$

$$CDI_{Dermal-soil} = \frac{C \times DFS \times ABSd \times 10^{-6}}{AT} \quad (9)$$

$$CDI_{Inhalation} - soil = \frac{C \times EF \times ED \times ET \times (1/24) \times (1/VF + 1/PEF)}{AT \times 1/1000} \quad (10)$$

In addition, carcinogenic risk through inhalation, oral, and dermal exposure pathways was computed by applying Eqs. (11-13):

$$Risk_{Inhalation} = CDI_{Inhalation\text{-}ca} \times IUR \quad (11)$$

$$Riski_{Ingestion} = CDI_{Oral\text{-}ca} \times CSF_{ing} \quad (12)$$

$$Risk_{dermal} = [CDI_{Dermal\text{-}ca} \times CSF_{ing}]/ABS_{GI} \quad (13)$$

According to *Cui et al.* [54], ABS_{GI} denotes dermal absorption factors (0.03, 0.001, and 0.01 for As, Cd, and other heavy metals, respectively). The total risk can be derived using Eq. (14):

$$Total\ risk = \Sigma\ Risk = Risk_{Inhalation} + Risk_{Oral} + Risk_{Dermal} \quad (14)$$

The total number of cancers over a lifetime is obtained by multiplying the cancer risk in the study area population [55-60]. Risks lying in the range of 1.00E−06 to 1.00 E−04 are regarded as tolerable. Risks below 1.00E−06 are not considered to have significant health effects. Finally, risks exceeding 1.00E−04 are viewed as unacceptable [61-63].

Non-carcinogenic risk

In the group of non-carcinogenic effects, there is no possibility of emerging non-carcinogenic health complications for a person, or it is extremely weak unless the amount of human contact with the desired pollution reaches a certain threshold. If the obtained HQ is greater than one, it means that people in contact with this pollution are exposed to non-carcinogenic health complications. Non-carcinogenic CDI through inhalation, oral, and dermal exposure was calculated using Eqs. (15-18) as follows [53]:

$$CDI_{Inhalation-air} = \frac{C \times EF \times ED \times ET \times (1\ day/24hours)}{AT \times (1000\mu g/1mg)} \quad (15)$$

$$CDI_{oral-soil} = \frac{C \times EF \times ED \times IRS \times RBA \times 10^{-6}}{AT \times BW} \quad (16)$$

$$CDI_{Dermal-soil} = \frac{C \times EF \times ED \times SA \times AF \times ABSd \times 10^{-6}}{AT \times BW} \quad (17)$$

$$CDI_{Inhalation-soil} = \frac{C \times EF \times ED \times ET \times (1/24) \times (1/VF + 1/PEF)}{AT} \quad (18)$$

HQ through inhalation, oral, and dermal exposure was calculated by Eq. (19):

$$HQ = CDI_{nc}/RfD \quad (19)$$

The HI can be derived using Eq. (20):

Table 3: Variables used for calculating the chronic daily intake.

Parameter	Unit	Values	Data source
Exposure Frequency (EF_{res})	days/year	350	[64]
Resident Exposure Time (ET_{res})	Hours/day	24	[64]
Lifetime (LT)	years	70	[64]
Body/weight-adult (BW_{res-a})	kg	70	[56]
Body weight- child (BW_{res-c})	kg	15	[64]
Exposure Duration (ED_{res})	years	70	[60]
Exposure Duration-child (ED_{res-c})	years	14	[64]
Surface area-adult ($SA_{res-a-soil}$)	Cm^2	5700	[64]
Surface area- child ($SA_{res-c\ soil}$)	Cm^2	2800	[64]
Ingestian Rate adult (IRS_{res-a})	mg/day	100	[64]
Ingestian Rate child (IRS_{res-c})	mg/day	200	[64]
Adherence factor –adult (AF_{res-a})	mg/cm^2	0.07	[64]
Adherence factor –child (AF_{res-c})	mg/cm^2	0.2	[64]
Fraction of vegetative cover (V)	-	0.5	[64]
Mean Annual wind speed (U_m)	m/s	2	[60]
Averaging time (AT)	days/year	ED×365	[64]
Averaging time (AT)	days/year	LT×365	[64]
Ingestion Rate-age-adjusted ($IFS_{ras-adj}$)	mg/kg	93333.33	-
Dermal content factor age-adjusted ($DFS_{res-adj}$)	mg/kg	294653.33	-

Table 4: Specific guideline parameters used in lifetime health risk assessments.

	R_{fC}	Data source	IUR	Data source	R_{fD}	Data source	SF_o	Data source
As	1.50E-05	[65]	4.20E-03	[64]	3.00E-04	[64]	1.50E-00	[64]
Pb	-	-	1.20E-05	[65]	-	-	8.50E-03	[65]
Ni	1.40E-05	[64]	2.40E-04	[64]	1.10E-02	[8]	9.10E-01	[65]
Zn	-	-	-	-	3.00E-03	[64]	-	-
Cr	1.00E-04	[64]	8.40E-02	[53]	3.00E-03	[64]	5.00E-01	[64]
Cu	-	-	-	-	4.00E-02	[53]	-	-
Cd	1.00E-05	[53]	1.8 E-03	[61]	5.00E-04	[53]	-	-

$$HI = HQ_{Inhalation} + HQ_{Oral} + HQ_{Dermal} \quad (20)$$

Table 3 presents the values related to the variables of the assessment equations of exposure to inhalation, ingestion, and skin contact of heavy metals. Some toxicological properties of heavy metals for cancer and non-cancer risk assessments are listed in Table 4.

Multivariate analysis and Monte-Carlo simulation

SPSS 20 software was used to perform all statistical analyses, including correlation between variables and multivariate analysis. The relationship between heavy metals and their possible sources was determined using cluster analysis. Cluster analysis is a statistical technique that is commonly used in environmental research.

Table 5: The average concentration of the studied heavy metals in the soil of Tehran (mg/kg).

Districts	As	Pb	Ni	Zn	Cr	Cu	Cd
1	4.4	22	20	56	31	39	1.9
2	5.9	38	24	88	39	45	1.9
3	4.5	29	21	63	41	47	1.7
4	6.6	31	26	91	54	52	2.4
5	7.3	30	35	113	33	64	2.6
6	10.4	46	31	138	30	42	2.5
7	11.6	35	30	88	56	46	2.7
8	9.5	52	29	123	61	65	2.2
9	8.4	40	25	105	47	71	2.4
10	6.5	42	29	110	56	36	2.2
11	9.7	48	32	99	38	52	2.4
12	11.16	59	36	87	66	57	1.8
13	12.31	88	38	165	76	81	2.9
14	12.5	69	33	144	44	68	2
15	11.55	57	31	130	72	66	3
16	9	44	28	112	66	40	2.5
17	10.2	55	34	117	75	39	2.4
18	6.8	79	40	122	63	49	3.3
19	11.46	81	33	152	72	71	3
20	13	85	37	130	84	62	3.5
21	8.9	31	26	79	48	34	2
22	7.5	25	29	64	39	42	1.6
Iran Standards	18	50	50	200	110	100	2
Europe standards	20	100	50	300	100	100	3
Min	4.4	22	20	56	30	36	1.6
Max	13	88	40	165	84	81	3.5
Ave	9.05	49.36	30.32	108	54.14	53.09	2.40

The cluster analysis method divides observations into two or more distinct unknown groups based on a combination of internal variables. Cluster analysis is frequently combined with Principal Component Analysis (PCA) to examine the results and group individual parameters and variables. Cluster analysis is used to create an organized system of observations in which people with similar characteristics are observed. In addition, the Kolmogorov-Smirnov test was used to assess the normality of heavy metal concentrations in this study. Afterward, the Ward method was used to perform hierarchical clustering on standard data sets. A population with a normal distribution is required for most statistical methods; otherwise, there are no reliability assumptions. Besides, the error rate will rise as the estimation process progresses, and the required validity will decline.

The present study analyzed the variability and sensitivity of risk assessment model predictions using the Monte-Carlo simulation method. For this purpose, Crystal Ball software, version 11.1.2.4 (Oracle), was used in Excel (2007).

RESULTS AND DISCUSSION

Table 5 lists the average concentrations of airborne metals in Tehran, with the highest (108) and the lowest (2.40) concentrations for Zn and Cd, respectively. Based on the concentration, the metals order is as follows: Zn > Cr > Cu > Pb > Ni > As > Cd. The results of the heavy metals distributions in the soil are illustrated in Figs. 2 and 3.

According to the concentration and distribution map of heavy metals in the soil, the concentrations of Ni and As in the south and east and somewhat in the center are more

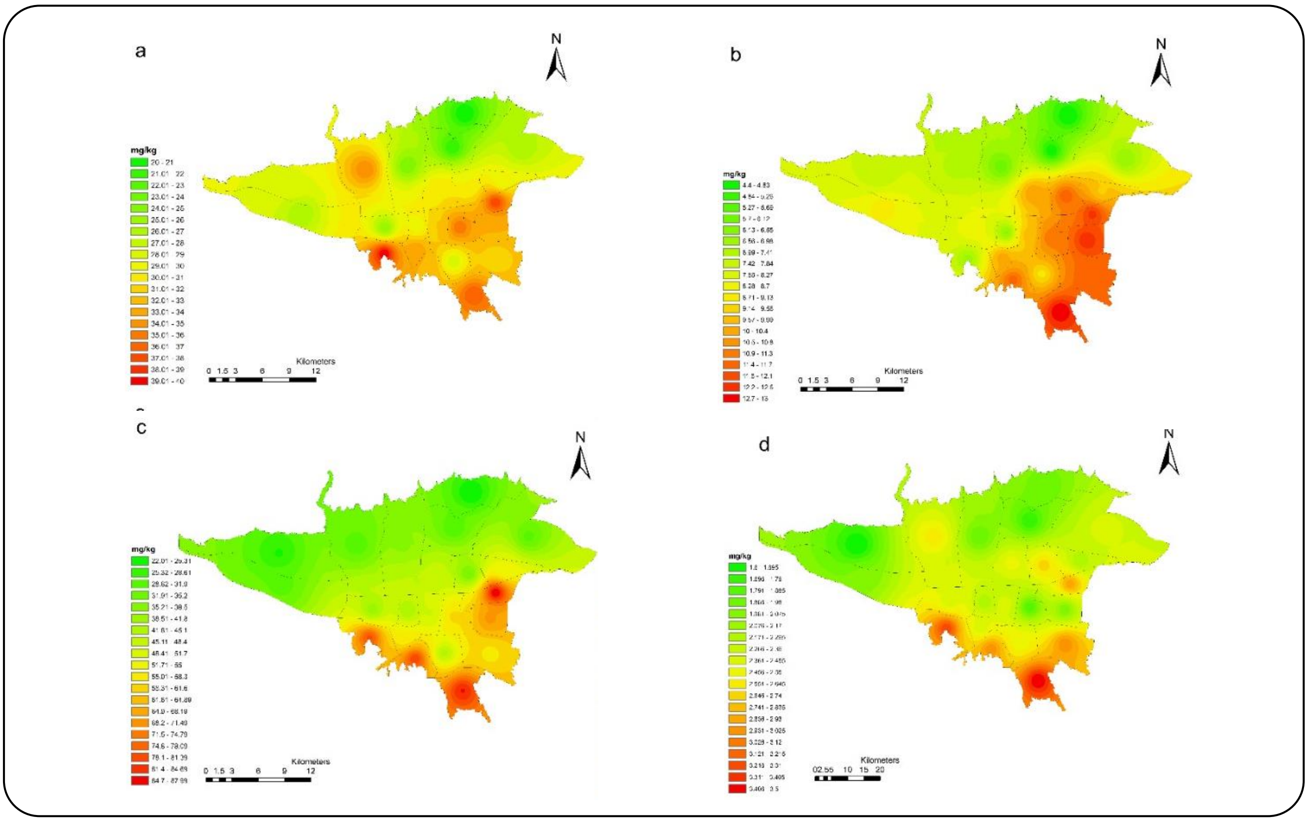


Fig. 2: Distribution of heavy metals (a=Ni, b=As, c=Pb, and d=Cd) in Tehran.

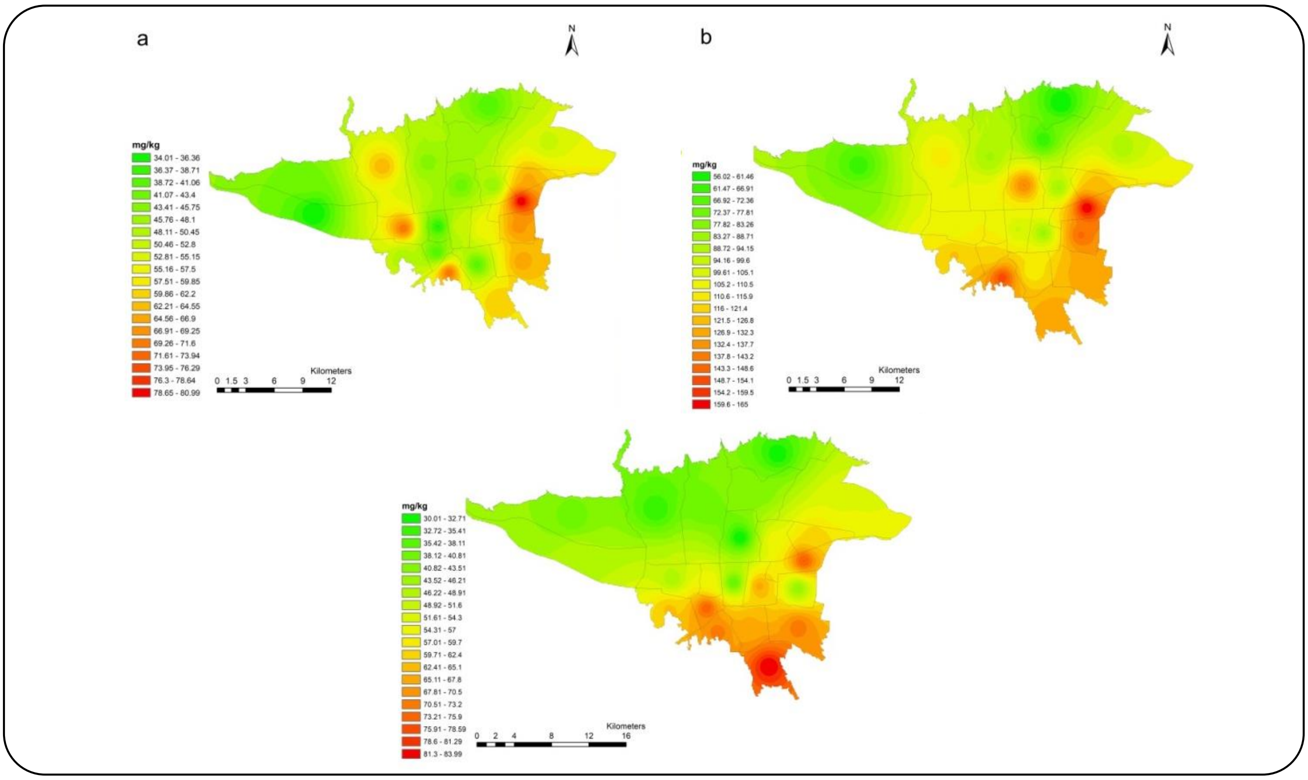


Fig. 3: Distribution of heavy metals (a=Cu, b=Zn, and c=Cr) in Tehran.

Table 6. The average concentration of heavy metals in the soil from different cities of the world compared with those of the study area.

Element	As	Pb	Ni	Zn	Cr	Cu	Cd	References
(mg/kg)	9.05	49.36	30.32	108	54.14	53.09	2.4	Present study
China1	27.77	30.74	67.37	85.86	0.074	25.81	0.19	[66]
Portugal	-	5.73	46.6	-	44	-	0.463	[67]
Austria	4.10	98.49	25.3	60.16	21.27	40.43	-	[36]
Greece	2.72	39.42	32.48	47.27	29.11	37.23	-	[36]
Serbia	2.85	49.33	35.24	51.54	28.93	30.69	-	[36]
Iran1	5.86	34.5	23.4	83.9	32.6	23.5	0.27	[37]
Iran2	-	41.15	35.78	62.93	67.46	42.2	2.74	[41]
Iran3	-	32.07	22.79	69.21	67.14	44.79	3.61	[42]
China2	12.15	50.13	31.14	155.33	73	40.77	-	[68]
Russia	8.4	28.3	46.5	77.7	106.9	40.8	-	[69]
Norway	3.3	32	43	80	81	32	-	[70]

than those of the other districts, while other metals in the south and east of the city have a higher concentration. Comparing the results of heavy metal concentrations in Tehran with the standard values of Iran and Europe reveals that the concentrations of As, Pb, Ni, Zn, Cr, and Cu are less than the standard levels, and only Cd is higher than the standard of Iran. In Table 6, the average concentrations from the studied metals are compared with those reported in other studies.

Comparing the results of the average concentration of heavy metals in this study with other studies in Iran and the world, the following results were obtained:

The concentration of As in this study is lower than in China and higher than in other studies. Also, the concentration of Pb is almost equal to the studies in Serbia and China and is higher than in other studies.

The average Ni concentration is almost equal to studies in Greece and China; the results of Zn studies are more than any study except China; Cr concentration is lower than Iran and Russia; and Cu concentration is higher than all studies. Finally, the concentration of Cd is almost equal to the Iranian research in this study.

The concentrations of heavy metals by the chemical partitioning method are presented in Tables 7 and 8.

The most significant advantage of using the chemical dissociation method is determining the human and natural origin of metals in the soil. The share originating from chemical dissociation is shown in Fig. 4. In addition, the results of the pollution index are presented in Fig. 5.

The heavy metals share originating from chemical dissociation can be expressed as follows:

Share of the anthropogenic origin:

Cd (86.01%)> Pb (46.59%)> Cr (25.75%)> As (24%)> Zn (11.53%)> Cu (7.35%)> Ni (4.09%)

Share of the natural origin:

Ni (95.91%)> Cu (92.65%)> Zn (88.47%)> As (76%)> Cr (74.24%)> Pb (53.41%)> Cd (13.99%)

The results of the pollution index demonstrate that the average pollution index of District 16 is the lowest and non-polluted while that of District 5 is the highest one and has a moderate level of pollution. Fig. 6 provides EF values in the soil of Tehran.

Table 7: The Anthropogenic share of heavy metals in the soil of Tehran.

Anthropogenic (mg/kg)	As	Pb	Ni	Zn	Cr	Cu	Cd
1	1.52	8	0.3	6	6	1.8	1.6
2	1.37	20	0.4	7	8	3.7	1.8
3	1.5	12	0.3	8	9	3.1	1.5
4	1.62	15	0.5	9	11	2.2	2.1
5	1.8	14	0.8	10	8	5.1	2.5
6	2.1	21	1.9	17	10	4.5	2.2
7	2.5	18	0.7	11	12	4.9	2.5
8	1.7	24	2.2	13	13	3.8	1.9
9	2	19	1.8	9	11	3.8	2.1
10	1.6	18	0.8	12	13	2.9	1.8
11	1.9	21	1	8	10	3.7	2
12	2.1	32	0.5	10	14	3.4	1.5
13	3.2	44	2.3	21	27	6.2	2.5
14	3.5	36	1.6	19	12	5.5	1.6
15	2.8	25	1.9	14	22	4.6	2.6
16	2.4	16	1.4	12	17	4.1	1.9
17	1.8	22	2	11	19	3.3	2.3
18	2.6	39	2.1	24	19	4.8	2.9
19	3.3	37	2.4	20	25	4	2.1
20	3	41	1.8	16	29	4.5	3
21	1.9	13	0.3	9	11	2	1.8
22	1.6	11	0.3	8	9	3.9	1.3
Min	1.37	8	0.3	6	6	1.8	1.3
Max	3.5	44	2.4	24	29	6.2	3
Ave	2.17	23	1.24	12.45	14.32	3.9	2.07

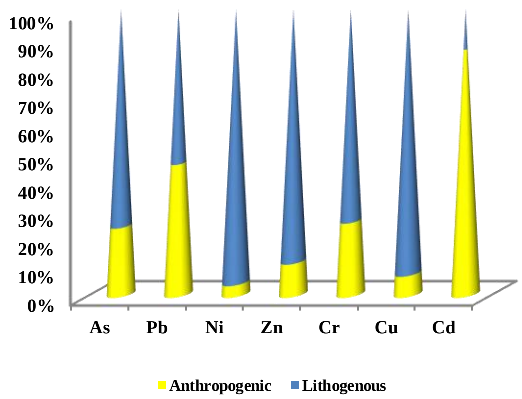


Fig. 4: The anthropogenic percentage share and lithogenous heavy metals in the soil of Tehran.

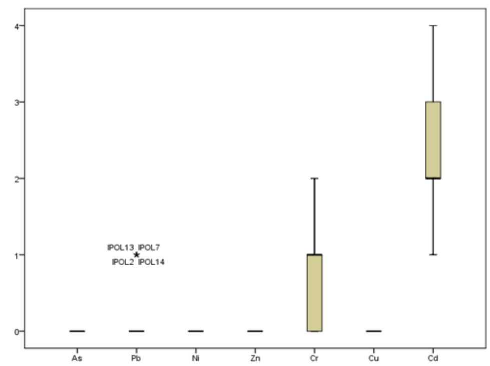


Fig. 5: Pollution indexes of heavy metals in urbanized area soils of Tehran.

Table 8: The lithogenous share of heavy metals in the soil of Tehran.

Lithogenous (mg/kg)	As	Pb	Ni	Zn	Cr	Cu	Cd
1	2.88	14	19.7	50	25	37.2	0.3
2	4.53	18	23.6	81	31	41.3	0.1
3	3	17	20.7	55	32	43.9	0.2
4	4.98	16	25.5	82	43	49.8	0.3
5	5.5	16	34.2	103	25	58.9	0.1
6	8.3	25	29.1	121	20	37.5	0.3
7	9.1	17	29.3	77	44	41.1	0.2
8	7.8	28	26.8	110	48	61.2	0.3
9	6.4	21	23.2	96	36	67.2	0.3
10	4.9	24	28.2	98	43	33.1	0.4
11	7.8	27	31	91	27	48.3	0.4
12	9.06	27	35.5	77	52	53.6	0.3
13	9.11	44	35.7	144	49	74.8	0.4
14	9	33	31.4	125	32	62.5	0.4
15	8.75	32	29.1	116	50	61.4	0.4
16	6.6	28	26.6	100	49	35.9	0.6
17	8.4	33	32	106	56	35.7	0.1
18	4.2	40	37.9	98	44	44.2	0.4
19	8.16	44	30.6	132	47	67	0.9
20	10	44	35.2	114	55	57.5	0.5
21	7	18	25.7	70	37	32	0.2
22	5.9	14	28.7	56	30	38.1	0.3
Min	2.88	14	19.7	50	20	32	0.1
Max	10	44	37.9	144	56	74.8	0.9
Ave	6.88	26.36	29.08	95.55	39.77	49.19	0.34

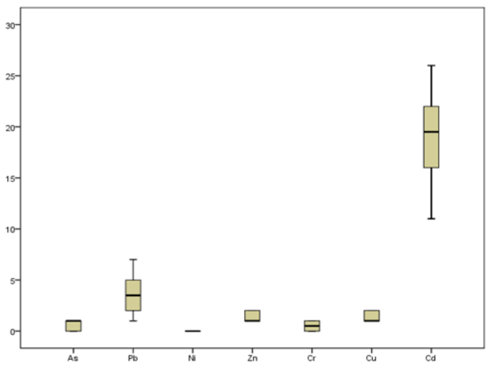


Fig. 6: Results of enrichment factors.

Based on the average EF, Pb and Cd are in the range of medium and significant enrichment, respectively, and other metals have minimal enrichment. Ecological RI values in the soil of Tehran are shown in Table 9.

The Ei results represent that all metals have low pollution in all districts except for Cd. This metal has a significant risk in the lowest case in District 19 but a serious risk in the highest case in District 5. Also, the ER of metals is low in District 19, significant in Districts 7 and 21, serious in Districts 2, 5, and 17, and moderate in other districts. The reason is the high Ei of Cd in all districts. Carcinogenic and non-carcinogenic risk assessments through oral, dermal, and inhalation exposure of heavy metals are shown in Tables 10 and 11, and Figs. 7 and 9.

Table 9: Ecological risk indexes values.

Ei	As	Pb	Zn	Cr	Cu	Cd	RI
1	15.28	7.86	1.12	2.48	5.24	190	221.98
2	13.02	10.56	1.09	2.52	5.45	570	602.64
3	15	8.53	1.15	2.56	5.35	255	287.59
4	13.25	9.69	1.11	2.51	5.22	240	271.78
5	13.27	9.38	1.1	2.64	5.43	780	811.82
6	12.53	9.2	1.14	3	5.6	250	281.47
7	12.75	10.29	1.14	2.55	5.6	405	437.33
8	12.18	9.29	1.12	2.54	5.31	220	250.44
9	13.13	9.52	1.09	2.61	5.28	240	271.63
10	13.27	8.75	1.12	2.6	5.44	165	196.18
11	13.44	8.89	1.09	2.81	5.38	180	211.61
12	12.32	10.93	1.13	2.54	5.32	180	212.24
13	13.51	10	1.15	3.1	5.41	218	251.17
14	13.89	10.45	1.15	2.75	5.44	150	183.68
15	13.2	8.9	1.12	2.88	5.37	225	256.47
16	13.64	7.86	1.12	2.69	5.57	125	155.88
17	12.14	8.33	1.1	2.68	5.46	720	749.71
18	16.19	9.88	1.24	2.86	5.54	248	283.71
19	14.04	9.2	1.15	3.06	5.3	100	132.75
20	13	9.66	1.14	3.05	5.39	210	242.24
21	12.71	8.61	1.13	2.59	5.31	300	330.35
22	12.71	8.93	1.14	2.6	5.51	160	190.89
Min	12.14	7.86	1.09	2.48	5.22	100	132.75
Max	16.19	10.93	1.24	3.1	5.6	780	811.82
Ave	13.39	9.31	1.13	2.71	5.41	278.68	310.62

Likewise, the total number of lifelong cancers is provided in Table 12. Figs. 8 and 10 illustrate the contribution of oral, dermal, and inhalation exposure pathways for assessing carcinogenic and non-carcinogenic risk.

According to the obtained results, the cancer risk of the studied metals is as follows: Based on a comparison of cancer risk with the standard provided by the EPA, which indicates the potential risks for cancer diseases, the cancer risks of As, Ni, and Cr are in the unacceptable range (Risk> 1E-04). Furthermore, the cancer risk of Pb and Cd metals is within acceptable limits (1.00E 06 risk 1.00 E 04) and has no significant health consequences (Risk 1.00E 06).

Cr and Ni have the highest cancer risk (Fig. 7), while Cr and Ni metals have a higher cancer rate because of their high concentrations and carcinogenic properties. As a result, the people of Tehran are exposed to various cancers due to inhaling, eating, and skin contact with the metal-contaminated soil.

Table 10: A summary of the results of carcinogenic risk.

	RISK	As	Pb	Ni	Cr	Cd	Total Risk
1	Oral	1.45E-05	6.83E-07	6.65E-05	5.66E-05	-	1.38E-04
	Dermal	2.28E-06	2.16E-08	5.25E-05	7.15E-05	-	1.26E-04
	Inhalation	1.20E-17	1.71E-19	3.11E-18	1.69E-15	2.22E-18	1.71E-15
2	Oral	1.94E-05	1.18E-06	7.89E-05	7.12E-05	-	1.71E-04
	Dermal	3.06E-06	3.72E-08	6.30E-05	9.00E-05	-	1.56E-04
	Inhalation	1.61E-17	2.95E-19	3.73E-18	2.12E-15	2.22E-18	2.14E-15
3	Oral	1.48E-05	9.00E-07	6.98E-05	7.49E-05	-	1.60E-04
	Dermal	2.34E-06	2.84E-08	5.51E-05	9.46E-05	-	1.52E-04
	Inhalation	1.22E-17	2.25E-19	3.27E-18	2.23E-15	1.98E-18	2.25E-15
4	Oral	2.17E-05	9.63E-07	8.64E-05	9.86E-05	-	2.08E-04
	Dermal	3.43E-06	3.04E-08	6.82E-05	1.25E-04	-	1.97E-04
	Inhalation	1.80E-17	2.41E-19	4.04E-18	2.94E-15	2.80E-18	2.97E-15
5	Oral	2.40E-05	9.32E-07	1.16E-04	6.03E-05	-	2.01E-04
	Dermal	3.79E-06	2.94E-08	9.18E-05	7.61E-05	-	1.72E-04
	Inhalation	1.99E-17	2.33E-19	5.44E-18	1.80E-15	3.03E-18	1.83E-15
6	Oral	3.42E-05	1.43E-06	1.03E-04	5.48E-05	-	1.93E-04
	Dermal	5.40E-06	4.51E-08	8.13E-05	6.92E-05	-	1.56E-04
	Inhalation	2.90E-17	3.58E-19	4.82E-18	1.63E-15	2.92E-18	1.67E-15
7	Oral	3.81E-05	1.09E-06	9.97E-05	1.02E-04	-	2.41E-04
	Dermal	6.02E-06	3.43E-08	7.87E-05	1.29E-04	-	2.14E-04
	Inhalation	3.16E-17	2.72E-19	4.66E-18	3.05E-15	3.15E-18	3.09E-15
8	Oral	3.12E-05	1.61E-06	9.64E-05	1.11E-04	-	2.40E-04
	Dermal	4.93E-06	5.10E-08	7.61E-05	1.41E-04	-	2.22E-04
	Inhalation	2.59E-17	4.04E-19	4.51E-18	3.23E-15	2.57E-18	3.26E-15
9	Oral	2.76E-05	1.24E-06	8.31E-05	8.58E-05	-	1.98E-04
	Dermal	4.36E-06	3.92E-08	6.56E-05	1.08E-04	-	1.78E-04
	Inhalation	2.29E-17	3.11E-19	3.89E-18	2.56E-15	2.80E-18	2.59E-15
10	Oral	2.14E-05	1.30E-06	9.64E-05	1.02E-04	-	2.21E-04
	Dermal	3.37E-06	4.12E-08	7.61E-05	1.29E-04	-	2.09E-04
	Inhalation	1.77E-17	3.27E-19	4.51E-18	3.05E-15	2.57E-18	3.08E-15
11	Oral	3.19E-05	1.49E-06	1.06E-04	6.94E-05	-	2.09E-04
	Dermal	5.03E-06	4.71E-08	8.40E-05	8.76E-05	-	1.77E-04
	Inhalation	2.64E-17	3.73E-19	4.98E-18	2.07E-15	2.80E-18	2.10E-15

Table 10: A summary of the results of carcinogenic risk.

	RISK	As	Pb	Ni	Cr	Cd	Total Risk
12	Oral	3.67E-05	1.83E-06	1.20E-04	1.21E-04	-	2.80E-04
	Dermal	5.79E-06	5.78E-08	9.45E-05	1.52E-04	-	2.52E-04
	Inhalation	3.04E-17	4.59E-19	5.60E-18	3.59E-15	2.10E-18	3.63E-15
13	Oral	4.05E-05	2.73E-06	1.26E-04	1.39E-04	-	3.08E-04
	Dermal	6.39E-06	8.63E-08	9.97E-05	1.75E-04	-	2.81E-04
	Inhalation	3.35E-17	6.84E-19	5.91E-18	4.14E-15	3.38E-18	4.18E-15
14	Oral	4.11E-05	2.14E-06	1.10E-04	8.04E-05	-	2.34E-04
	Dermal	6.49E-06	6.76E-08	8.66E-05	1.01E-04	-	1.94E-04
	Inhalation	3.40E-17	5.36E-19	5.13E-18	2.30E-15	2.33E-18	2.34E-15
15	Oral	3.80E-05	1.77E-06	1.03E-04	1.32E-04	-	2.75E-04
	Dermal	5.99E-06	5.59E-08	8.13E-05	1.66E-04	-	2.53E-04
	Inhalation	3.14E-17	4.43E-19	4.82E-18	3.92E-15	3.50E-18	3.96E-15
16	Oral	2.96E-05	1.37E-06	9.31E-05	1.21E-04	-	2.45E-04
	Dermal	4.67E-06	4.31E-08	7.35E-05	1.52E-04	-	2.30E-04
	Inhalation	2.45E-17	3.42E-19	4.35E-18	3.59E-15	2.92E-18	3.62E-15
17	Oral	3.35E-05	1.71E-06	1.13E-04	1.37E-04	-	2.85E-04
	Dermal	5.29E-06	5.39E-08	8.92E-05	1.73E-04	-	2.68E-04
	Inhalation	2.78E-17	4.28E-19	5.29E-18	4.08E-15	3.03E-18	4.12E-15
18	Oral	2.24E-05	2.45E-06	1.33E-04	1.15E-04	-	2.73E-04
	Dermal	3.53E-06	7.74E-08	1.04E-04	1.45E-04	-	2.53E-04
	Inhalation	1.85E-17	6.14E-19	6.22E-18	3.43E-15	3.85E-18	3.46E-15
19	Oral	3.77E-05	2.52E-06	1.10E-04	1.32E-04	-	2.82E-04
	Dermal	5.95E-06	7.94E-08	8.66E-05	1.66E-04	-	2.59E-04
	Inhalation	3.12E-17	6.30E-19	5.13E-18	3.92E-15	3.50E-18	3.96E-15
20	Oral	4.27E-05	2.64E-06	1.23E-04	1.53E-04	-	3.21E-04
	Dermal	6.75E-06	8.33E-08	9.71E-05	1.94E-04	-	2.98E-04
	Inhalation	3.54E-17	6.61E-19	5.75E-18	4.57E-15	3.97E-18	4.62E-15
21	Oral	2.93E-05	9.63E-07	8.64E-05	8.77E-05	-	2.04E-04
	Dermal	4.62E-06	3.04E-08	6.82E-05	1.11E-04	-	1.84E-04
	Inhalation	2.42E-17	2.41E-19	4.04E-18	2.61E-15	2.33E-18	2.64E-15
22	Oral	2.47E-05	7.76E-07	9.64E-05	7.12E-05	-	1.93E-04
	Dermal	3.89E-06	2.45E-08	7.61E-05	9.00E-05	-	1.70E-04
	Inhalation	2.04E-17	1.94E-19	4.51E-18	2.12E-15	1.87E-18	2.15E-15
	Total Risk	7.58E-04	3.48E-05	3.97E-03	4.92E-03	6.18E-17	9.68E-03

Table 11: The results of non-carcinogenic risk for different exposure pathways.

	HQ	As	Ni	Zn	Cr	Cu	Cd	HI
1	Oral	1.21E-02	2.49E-03	2.56E-04	1.42E-02	1.34E-03	5.21E-03	3.56E-02
	Dermal	2.24E-03	9.94E-05	1.02E-05	5.65E-04	5.33E-05	4.15E-04	3.38E-03
	Inhalation	1.90E-13	9.36E-13	-	2.01E-13	-	1.23E-13	1.45E-12
2	Oral	1.62E-02	2.99E-03	4.02E-04	1.78E-02	1.54E-03	5.21E-03	4.41E-02
	Dermal	3.22E-03	1.19E-04	1.60E-05	7.11E-04	6.15E-05	4.15E-04	4.54E-03
	Inhalation	2.55E-13	1.11E-12	-	2.53E-13	-	1.23E-13	1.74E-12
3	Oral	1.23E-02	2.62E-03	2.88E-04	1.87E-02	1.61E-03	4.66E-03	4.02E-02
	Dermal	2.46E-03	1.04E-04	1.15E-05	7.47E-04	6.42E-05	3.72E-04	3.76E-03
	Inhalation	1.94E-13	9.72E-13	-	2.66E-13	-	1.10E-13	1.54E-12
4	Oral	1.81E-02	3.24E-03	4.16E-04	2.47E-02	1.78E-03	6.58E-03	5.48E-02
	Dermal	3.61E-03	1.29E-04	1.66E-05	9.84E-04	7.11E-05	5.25E-04	5.34E-03
	Inhalation	2.85E-13	1.20E-12	-	3.50E-13	-	1.55E-13	1.99E-12
5	Oral	2.00E-02	4.36E-03	5.16E-04	1.51E-02	2.19E-03	7.12E-03	4.93E-02
	Dermal	3.99E-03	1.74E-04	2.06E-05	6.01E-04	8.75E-05	5.68E-04	5.44E-03
	Inhalation	3.15E-13	1.62E-12	-	2.14E-13	-	1.68E-13	2.32E-12
6	Oral	2.84E-02	3.86E-03	6.30E-04	1.37E-02	1.44E-03	6.85E-03	5.49E-02
	Dermal	5.68E-03	1.54E-04	2.51E-05	5.47E-04	5.74E-05	5.47E-04	7.01E-03
	Inhalation	4.49E-13	1.43E-12	-	1.94E-13	-	1.62E-13	2.24E-12
7	Oral	3.18E-02	3.74E-03	4.02E-04	2.56E-02	1.58E-03	7.40E-03	7.05E-02
	Dermal	6.34E-03	1.49E-04	1.60E-05	1.02E-03	6.29E-05	5.90E-04	8.18E-03
	Inhalation	5.01E-13	1.39E-12	-	3.63E-13	-	1.75E-13	2.43E-12
8	Oral	2.60E-02	3.61E-03	5.57E-04	2.79E-02	2.23E-03	6.03E-03	6.63E-02
	Dermal	5.19E-03	1.44E-04	2.22E-05	1.11E-03	8.88E-05	4.81E-04	7.04E-03
	Inhalation	4.10E-13	1.43E-12	-	3.95E-13	-	1.43E-13	2.38E-12
9	Oral	2.30E-02	3.11E-03	4.79E-04	2.15E-02	2.43E-03	6.58E-03	5.71E-02
	Dermal	4.59E-03	1.24E-04	1.91E-05	8.56E-04	9.70E-05	5.25E-04	6.21E-03
	Inhalation	3.63E-13	1.16E-12	-	3.05E-13	-	1.55E-13	1.98E-12
10	Oral	1.78E-02	3.61E-03	5.02E-04	2.56E-02	1.23E-03	6.03E-03	5.48E-02
	Dermal	3.55E-03	1.44E-04	2.00E-05	1.02E-03	4.92E-05	4.81E-04	5.26E-03
	Inhalation	2.81E-13	1.34E-12	-	3.63E-13	-	1.43E-13	2.13E-12
11	Oral	2.66E-02	3.99E-03	4.52E-04	1.74E-02	1.78E-03	6.58E-03	5.68E-02
	Dermal	5.30E-03	1.59E-04	1.80E-05	6.92E-04	7.11E-05	5.25E-04	6.77E-03
	Inhalation	4.19E-13	1.48E-12	-	2.46E-13	-	1.55E-13	2.30E-12
12	Oral	3.06E-02	4.48E-03	3.97E-04	3.01E-02	1.95E-03	4.93E-03	7.25E-02
	Dermal	6.10E-03	1.79E-04	1.59E-05	1.20E-03	7.79E-05	3.94E-04	7.97E-03
	Inhalation	4.82E-13	1.67E-12	-	4.28E-13	-	1.17E-13	2.70E-12

Table 11: The results of non-carcinogenic risk for different exposure pathways.

	HQ	As	Ni	Zn	Cr	Cu	Cd	HI
13	Oral	3.37E-02	4.73E-03	7.53E-04	3.47E-02	2.77E-03	7.95E-03	8.46E-02
	Dermal	6.73E-03	1.89E-04	3.01E-05	1.38E-03	1.11E-04	6.34E-04	9.07E-03
	Inhalation	5.32E-13	1.76E-12	-	4.92E-13	-	1.88E-13	2.97E-12
14	Oral	3.42E-02	4.11E-03	6.58E-04	2.01E-02	2.33E-03	5.48E-03	6.69E-02
	Dermal	6.83E-03	1.64E-04	2.62E-05	8.02E-04	9.29E-05	4.37E-04	8.35E-03
	Inhalation	5.40E-13	1.53E-12	-	2.58E-13	-	1.30E-13	2.46E-12
15	Oral	3.16E-02	3.86E-03	5.94E-04	3.29E-02	2.26E-03	8.22E-03	7.94E-02
	Dermal	6.31E-03	1.54E-04	2.37E-05	1.31E-03	9.02E-05	6.56E-04	8.54E-03
	Inhalation	4.99E-13	1.43E-12	-	4.66E-13	-	1.94E-13	2.59E-12
16	Oral	2.47E-02	3.49E-03	5.11E-04	3.01E-02	1.37E-03	6.85E-03	6.70E-02
	Dermal	4.92E-03	1.39E-04	2.04E-05	1.20E-03	5.47E-05	5.47E-04	6.88E-03
	Inhalation	3.89E-13	1.30E-12	-	4.28E-13	-	1.62E-13	2.28E-12
17	Oral	2.79E-02	4.23E-03	5.34E-04	3.42E-02	1.34E-03	7.12E-03	7.53E-02
	Dermal	5.58E-03	1.69E-04	2.13E-05	1.37E-03	5.33E-05	5.68E-04	7.76E-03
	Inhalation	4.41E-13	1.57E-12	-	4.86E-13	-	1.68E-13	2.67E-12
18	Oral	1.86E-02	4.98E-03	5.57E-04	2.88E-02	1.68E-03	9.04E-03	6.37E-02
	Dermal	3.72E-03	1.99E-04	2.22E-05	1.15E-03	6.70E-05	7.21E-04	5.88E-03
	Inhalation	2.94E-13	1.85E-12	-	4.08E-13	-	2.14E-13	2.77E-12
19	Oral	3.14E-02	4.11E-03	6.94E-04	3.29E-02	2.43E-03	8.22E-03	7.98E-02
	Dermal	6.26E-03	1.64E-04	2.77E-05	1.31E-03	9.70E-05	6.56E-04	8.51E-03
	Inhalation	4.95E-13	1.53E-12	-	4.66E-13	-	1.94E-13	2.69E-12
20	Oral	3.56E-02	4.61E-03	5.94E-04	3.84E-02	2.12E-03	9.32E-03	9.06E-02
	Dermal	7.11E-03	1.84E-04	2.37E-05	1.53E-03	8.47E-05	7.43E-04	9.68E-03
	Inhalation	5.62E-13	1.71E-12	-	5.44E-13	-	2.20E-13	3.04E-12
21	Oral	2.44E-02	3.24E-03	3.61E-04	2.19E-02	1.16E-03	5.48E-03	5.65E-02
	Dermal	4.86E-03	1.29E-04	1.44E-05	8.75E-04	4.65E-05	4.37E-04	6.36E-03
	Inhalation	3.84E-13	1.20E-12	-	3.11E-13	-	1.30E-13	2.03E-12
22	Oral	2.05E-02	3.61E-03	2.92E-04	1.78E-02	1.44E-03	4.38E-03	4.80E-02
	Dermalmal	4.10E-03	1.44E-04	1.17E-05	7.11E-04	5.74E-05	3.50E-04	5.37E-03
	Inhalation	3.24E-13	1.34E-12	-	2.53E-13	-	1.04E-13	2.02E-12
	HI	6.54E-01	8.64E-02	1.13E-02	5.66E-01	4.16E-02	1.57E-01	1.52E+00

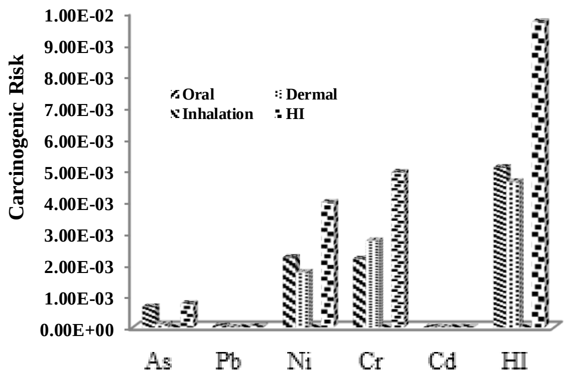


Fig. 7: Non-carcinogenic risk for oral, dermal, and inhalation exposure pathways.

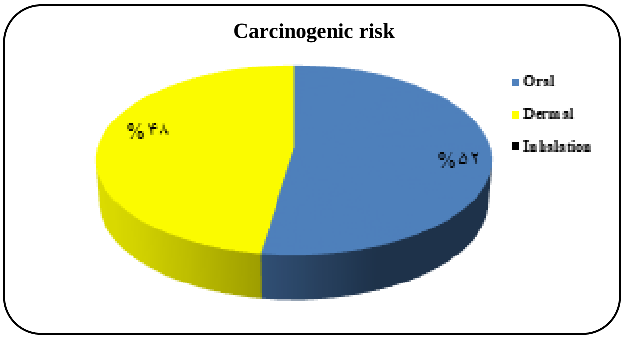


Fig. 8: The contribution of oral, dermal, and inhalation exposure pathways for carcinogenic risk assessment.

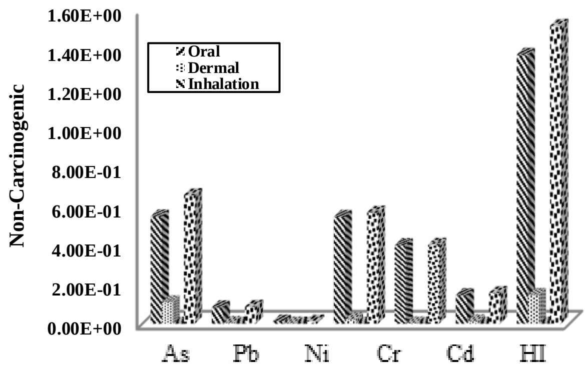


Fig. 9: Non-carcinogenic risk for oral, dermal, and inhalation exposure pathways.

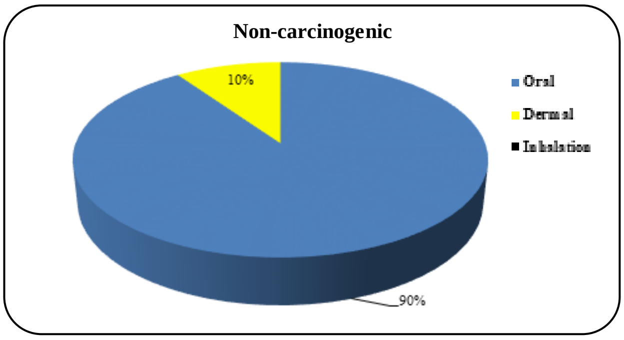


Fig. 10: The contribution of oral, dermal, and inhalation exposure pathways for non-carcinogenic risk assessment.

Fig. 8 shows that eating accounted for the most non-cancer risk assessment (52%), followed by skin absorption (48%). Finally, the total number of cancers over a lifetime was calculated by multiplying the cancer risk in each district's population by the number of cancers per person. Furthermore, the total number of cancers caused by exposure pathways over a lifetime is 3,739. In other words, 3739 Tehran residents are diagnosed with various cancers during their 70-year lives. It means that about 53 people are diagnosed with cancer every year after coming into contact with heavy metals in Tehran's soil.

The HQ values of As, Ni, Cr, and Cd were less than the safe level (HQ 1), as shown in Table 10. The highest HQ value is 6.54E-01 for As, and the highest HQ value is 1.13E-02 for Zn. The total HI value (= 1.52E + 00) indicates that non-cancerous respiratory hazards are incredibly high.

According to Fig. 9, Cd, As, and Cr have the highest non-cancerous risks. As a result, the people of Tehran are exposed to various non-cancerous diseases due to inhaling, eating, and skin contact with metal-contaminated soil. As shown in Fig. 10, eating accounted for 90% of non-cancer risk assessment, followed by skin absorption, which accounted for about 10%. The risk assessment results demonstrate that the total risk of heavy metals in the soil of Tehran is oral (5.08E-03), dermal (4.60E-03), and through inhalation (6.54E-14). The non-cancer risk assessment results designate that the RI of all heavy metals in the soil of Tehran is oral (1.13E-00), dermal (1.47E-01), and through inhalation (5.07E-11).

The number of cancers during the lifetime indicates the number of people suffering from different cancers through various routes of exposure to the soil (assuming a lifespan of 70 years). As mentioned before, the number of cancers in a lifetime is equal to 3,739.

The simulation results of non-cancerous risk evaluation of heavy metals in the soil of Tehran by the Monte Carlo uncertainty method are shown in Figs. 11 (a-f).

The results of the non-cancerous risk evaluation, which is performed based on the uncertainty of the Monte Carlo,

Table 12: Number of cancers during the lifetime of Tehran citizens in contact with the soil

	Total Risk	population
1	2.65E-04	493889
2	3.27E-04	692579
3	3.12E-04	330004
4	4.04E-04	917261
5	3.73E-04	856565
6	3.49E-04	250753
7	4.55E-04	312002
8	4.62E-04	425044
9	3.76E-04	174115
10	4.30E-04	326885
11	3.85E-04	308176
12	5.32E-04	240909
13	5.89E-04	253054
14	4.28E-04	489101
15	5.28E-04	659468
16	4.75E-04	267678
17	5.53E-04	278354
18	5.25E-04	419249
19	5.41E-04	255533
20	6.19E-04	367600
21	3.88E-04	186319
22	3.63E-04	175398

indicate that none of the metals has a risk greater than 1. Therefore, such metals alone do not create any non-cancerous complications that could affect people’s health.

The average evaluation of the uncertainty of being non-cancerous for As is about 3.02E-02 ± 9.66E-05. In 95% of all cases, and with a 90% confidence level, the risk index is less than 4.69E-02. It means the people of this region are not exposed to the non-cancerous disease through eating, breathing, or skin-contacting with As metal.

The results of the Monte Carlo’s uncertainty of non-cancerous evaluation for Ni show that its concentration is 3.95E03 ± 9.16E-06. The non-cancerous risk index with a 90% confidence level was less than 1.88E-02 for 95% of all cases, suggesting the lack of non-cancerous disease in the population of this region through breathing, eating, or skin-contacting with the Ni of soil.

The results of the uncertainty of being non-cancerous for the Zn indicate that the concentration of this metal is 5.20E-02 ± 1.63E-04, which is less than 8.08E-02 in 95% of all cases (with a 90% confidence level). It means that people will not catch the non-cancerous disease through breathing, eating, or skin-contacting.

The Monte Carlo’s uncertainty of non-cancerous evaluation results for Cr shows that its average concentration is 2.59E-02 ± 8.73E-05. The amount of risk index for being non-cancerous is less than 4.10E-02 in 95% of all cases (with a 90% confidence level). This outcome suggests there is no risk of getting infected by non-cancerous disease for the population of this region through breathing, eating, or skin-contacting with Cr of the soil.

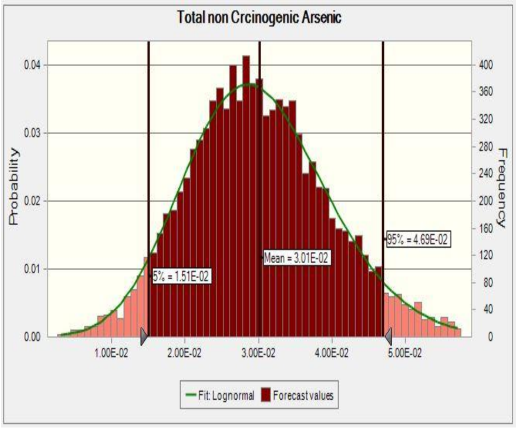
The Monte Carlo’s uncertainty of non-cancerous evaluation results for the Cu shows its concentration is 1.90E-03 ± 5.70E-06. The risk index value for being non-cancerous is less than 2.89E-03 in 95% of all cases (with a 90% confidence level). It indicates that there is no risk of being infected by non-cancerous disease for the population of this region through breathing, eating, or skin-contacting with the soil Cu.

Simulating the non-cancerous risk of Cd of soil revealed that the concentration of Cu is 9.85E-03 ± 1.80E-05 (with 90% confidence level). The HI amount of Cd is less than 9.85E-03 in 95% of all cases (with a 90% confidence level), suggesting that non-cancerous disease does not arise from breathing, eating, or skin-contacting with this metal in the soil.

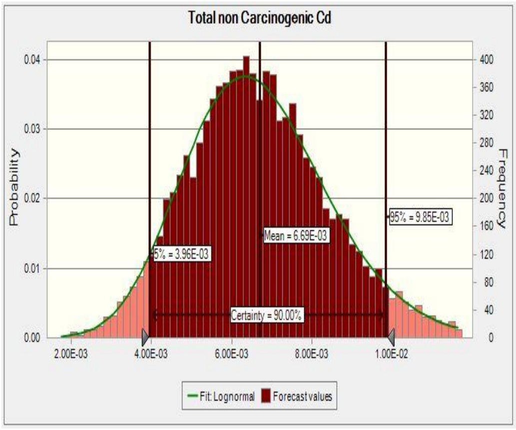
Sensitivity analysis results of exposure risk to heavy metals in the soil of Tehran are shown in Figs.12 (a-e).

Cancer risk simulation results of exposure to metals of soils show that 95% of the risk of getting cancer through breathing, eating, and skin-contacting is as follows: For As, it is less than 2.11E-05 (1.35E-05 ± 4.35E-08); for Pb metal, it is less than 1.06E-06 (6.02E-07 ± 2.68E-09); and for Ni, it is less than 9.17E-08 (3.95E-05 ± 9.17E-08). Moreover, with 0.95 certainties, the risk of getting cancer through breathing, eating, or skin-contacting with Cr is 6.16E-05 in the maximum amount (3.88E-05 ± 1.31E-07), and for the Cd, it is 1.30E-06 (8.27E-07 ± 2.58E-09).

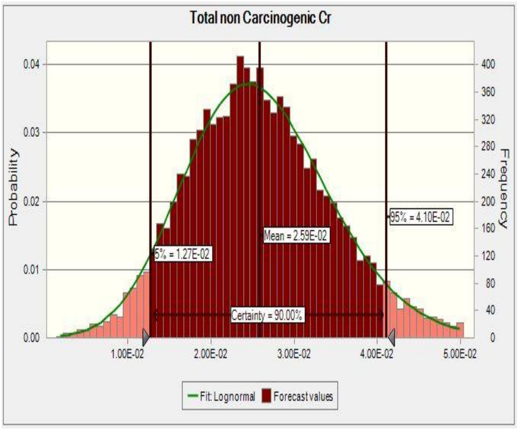
Sensitivity analysis results of exposure risk to heavy metals in the soil of Tehran are shown in Figs.13 (a-g).



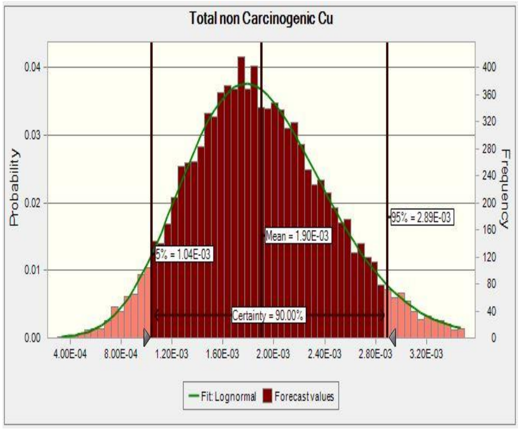
(a). Hazard Quotient values of As for different exposure pathways



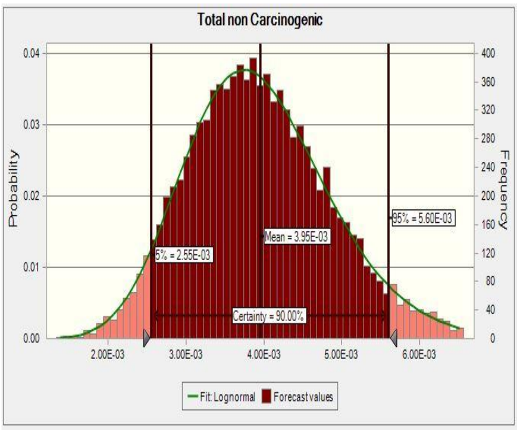
(b). Hazard Quotient values of Cd for different exposure pathways



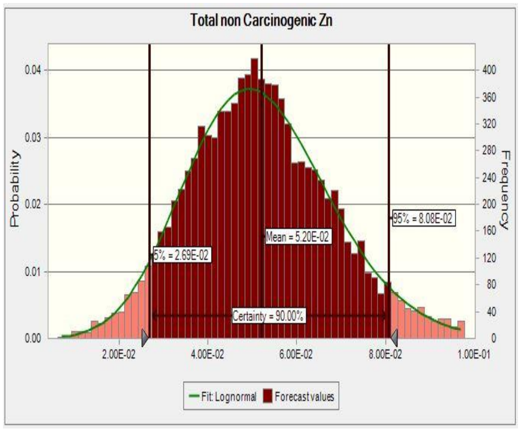
(c). Hazard Quotient values of Cr for different exposure pathways



(d). Hazard Quotient values of Cu for different exposure pathways

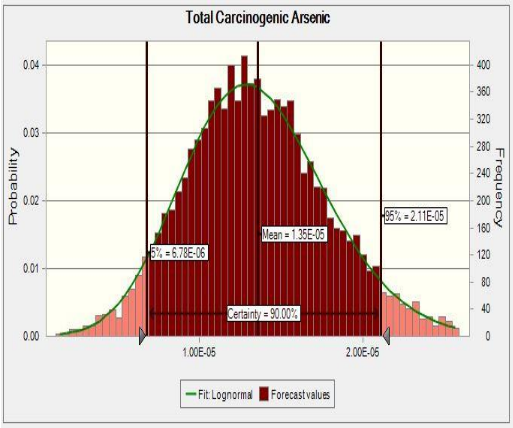


(e). Hazard Quotient values of Ni for different exposure pathways

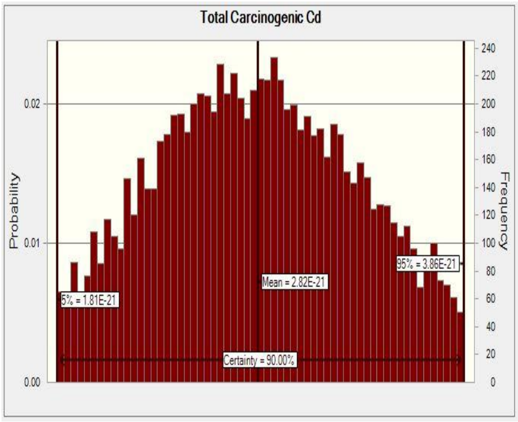


(f). Hazard Quotient values of Zn for different exposure pathways

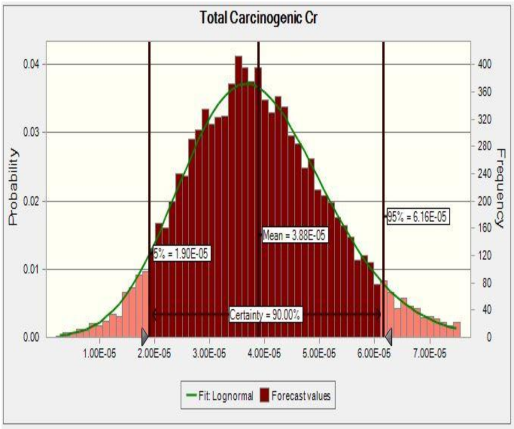
Fig. 11: Monte Carlo uncertainty histogram for non-cancerous risk evaluation of heavy metals studied in Tehran.



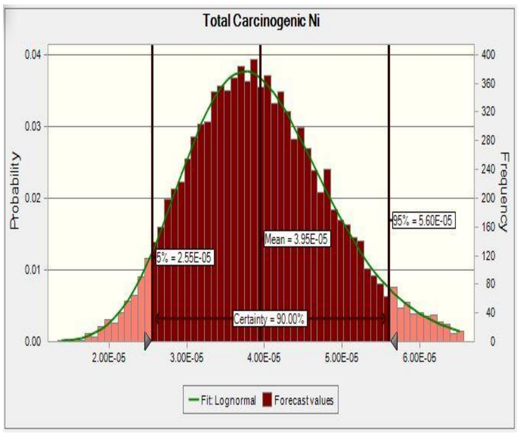
(a). Carcinogenic Risk values of As for different exposure pathways



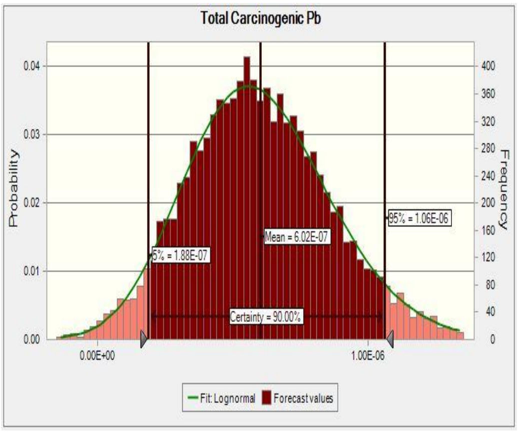
(b). Carcinogenic Risk values of Cd for different exposure pathways



(c). Carcinogenic Risk values of Cr for different exposure pathways

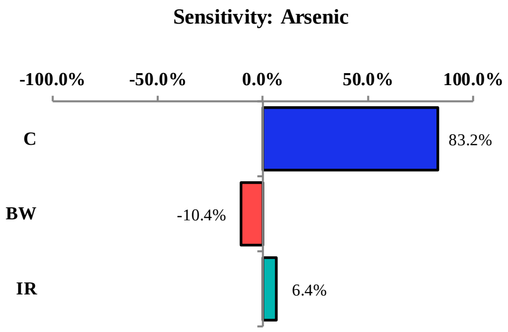


(d). Carcinogenic Risk values of Ni for different exposure pathways

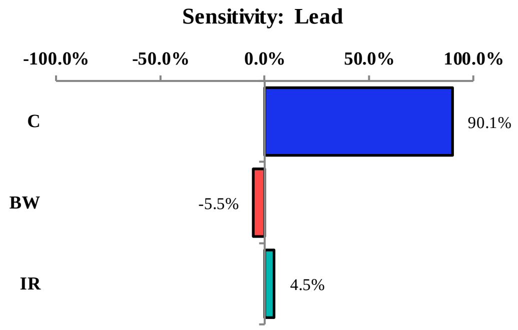


(e). Carcinogenic Risk values of Pb for different exposure pathways

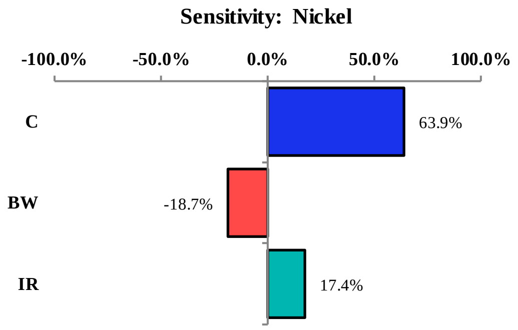
Fig. 12. Monte Carlo uncertainty histogram for cancerous risk evaluation of heavy metals studied in Tehran.



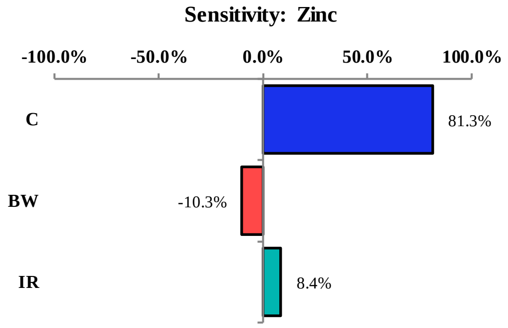
a. Histogram of Arsenic sensitivity analysis of the risk in Tehran's soil



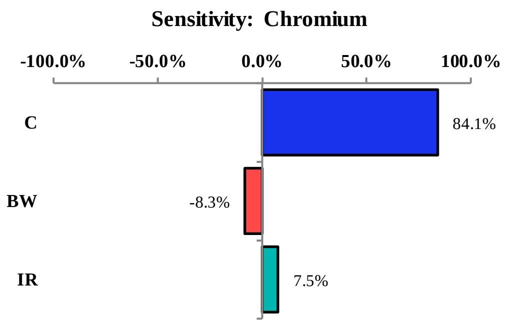
b. Histogram of Lead sensitivity analysis of the risk in Tehran's soil



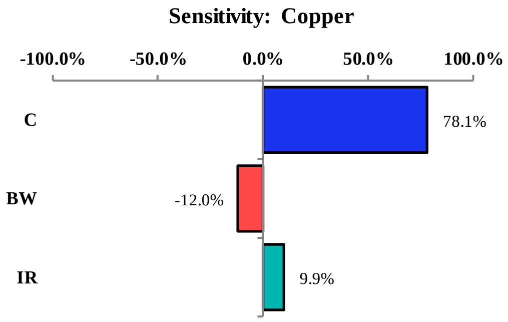
c. Histogram of nickel sensitivity analysis of the risk in Tehran's soil



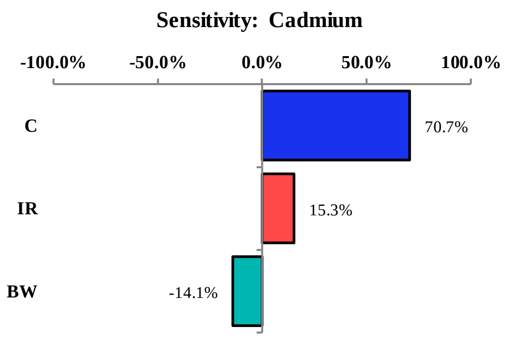
d. Histogram of zinc sensitivity analysis of the risk in Tehran's soil



e. Histogram of chromium sensitivity analysis of the risk in Tehran's soil



f. Histogram of copper sensitivity analysis of the risk in Tehran's soil



g. Histogram of cadmium sensitivity analysis of the risk in Tehran's soil

Fig. 13: Histogram of heavy metal sensitivity analysis of the risk in Tehran's soil.

Sensitivity analysis of the risk of exposure to As through the soil showed that the concentration of this element increases the risk by 83.2%. Thus, increasing concentration by one unit increases the risk by 83.2%. Bodyweight reduces the risk by 10.4% such that by increasing 1 kg of body weight, it reduces the risk by 10.4%. Also, the consumption level increases the risk by 6.4%.

The sensitivity analysis results of the risk of exposure to Pb showed that a 1-unit increase in concentration leads to a 90.1% increase in the risk level. Besides, increasing the body weight by 1 kg lowers the risk by 5.5%, while increasing the amount of consumption raises the risk by 4.5%.

The results of risk sensitivity analysis for exposure to Ni show that increasing its concentration and consumption increase the risk by 63.9% and 17.4%, respectively. Besides, increasing body weight lowers the risk by 18.7%.

The sensitivity analysis results of the risk of exposure to Zn indicate that the concentration of this metal has increased the risk by 81.3%. Weight gain reduces the risk by 10.4%. It also increases the consumption rate on risk by 8.4%.

Risk sensitivity analysis of exposure to Cr indicates that a one-unit increase in concentration and consumption rate increases the risk by 84.1 and 7.5%, respectively, and a one-unit increase in body weight reduces the risk by 8.3%.

The risk sensitivity analysis of Cu exposure in soil shows that increasing the concentration and consumption rate increases the risk by 78.1 and 9.9%, respectively. Moreover, a one-unit increase in body weight lowers the risk by 12%.

Sensitivity analysis results of the risk of exposure to Cd show that a one-unit increase in concentration and consumption rate resulted in the risk increase by 70.7 and 15.3%, respectively. Also, a one-unit increase in body weight resulted in a 14.1% decrease in risk level.

The results obtained from the dendrogram of the discussed variables by the soil cluster analysis method (Fig. 14) revealed four clusters: 1) As and Cd, 2) Ni with metals of cluster one, 3) Pb, Cr, and Cu, and 4) Zn. As can be seen, Clusters 1 and 2 are close, and Cluster 3 is farther apart, making the main category A represent different human resources for these elements. Also, Cluster 4 alone made the main group B, which can be the source of this most natural metal emission.

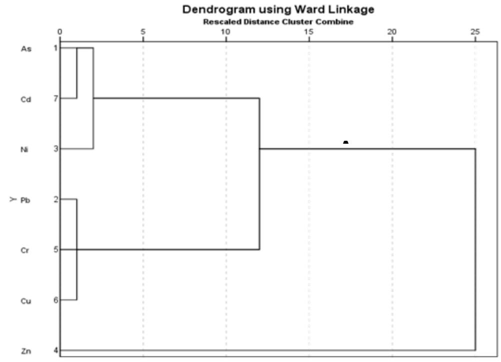


Fig. 14:. Dendrogram obtained from cluster analysis of heavy metals studied in Tehran's soil

Cluster analysis involves a series of multivariate methods applied to find real data sets. In the clustering process, similar variables are placed in the same class. Hierarchical cluster analysis is the most widely used method for identifying similar and dissimilar groups. The cluster tree connects equal weight options to create larger clusters and evaluates similarities between variables in this process. The present study analyzed the generated data sets using the Ward method to correlate the square Euclidean distance as a similarity criterion.

CONCLUSIONS

The chemical dissociation results reveal that Cd has an Anthropogenic origin, and the remaining metals are of Lithogenous origin. The average Ipoll of metals calculated based on chemical dissociation results indicates that all metals are in the contamination range except for Cd, which is moderate to highly contaminating. Comparing the average enrichment of metals with Hernandez's theory revealed that Cd and Pb have a human origin, and the remaining metals are of Earth's origin. Chemical dissociation also approves Hernandez's theory for all metals except for Pb. The average ER of all metals is low, excluding Cd that has a medium risk.

The risk assessment results represent a 95% probability of the infection of 3739 residents with various cancers and a probability of developing non-cancerous diseases at a rate of 1.52E+00 normal during 70 years of the life of the citizens. Generally, the evaluation results of the non-cancerous disease are consistent with those of Monte Carlo's uncertainty method. According to the obtained results, every heavy metal causes the non-cancerous disease to the region's people, but the total risk indicators of all metals are greater than 1. As a result, people may catch cancerous diseases in case of exposure to these metals. Generally, the sensitivity analysis results of exposure risk to heavy metals in the soil of Tehran showed that increasing the concentration and consumption rate increases the risk while increasing the body weight reduces the risk.

Further, the risk assessment results indicate that metal contamination in the soil through the oral pathway is the first and the main cause of various non-cancerous and cancerous diseases, followed by skin absorption. Generally, proper decisions must be made to manage pollution sources and control pollution by considering cancer treatment costs and adaptation to it, the costs of non-cancerous diseases, other social and economic costs, and the costs of climate change. The cluster analysis results indicate that the elements including As, Cd, Ni, Pb, Cr, and Cu originate mostly from potential human sources such as industrial and traffic activities, and the element Zn is predominantly of natural sources. However, future research requires methodological innovation and international standardization to tackle the multiple issues related to urban soils pollution and environmental health, and the research methods associated with environmental health data and risk assessment methods can be improved.

Limitations and suggestions

The main constraint of this study was the high cost of sampling equipment and the process of analysis. Monitoring air pollution of effective industries and vehicles and continuous measurement of suspended particles are recommended to perform control mechanisms and evaluate the extent of exposure and health effects, furthermore, localization of data used in risk assessment as well as performing risk assessment near industries are other suggestions.

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